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PROCEEDINGS OF THE THIRD SYMPOSIUM ON NONDESTRUCTIVE TESTING OF TIRES

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PROCEEDINGS OF THE THIRD SYMPOSIUM ON NONDESTRUCTIVE TESTING OF TIRES

Editor
PAUL E. J. VOGEL
Materials Manufacturing & Testing Technology Division
Army Materials and Mechanics Research Center

27-29 January 1976

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PREFACE

This Proceedings follows the format of those for the 1973 and 1975 symposia. Much new material had been presented in it, however, and while it appeared for a time that the subjects under discussion had reached a plateau, it now seems that new impetus has been given to failure analysis, its accompanying tools, and to methods of correlation of reliability testing and nondestructive techniques. It has become apparent that we must turn to fleet operators, their suppliers, and their rebuilders to join with the practitioners of the various disciplines to learn the significance of particular anomalies, to learn how and if the anomaly can be related to failure mechanisms, and to develop instrumentation that can detect significant anomalies at the earliest possible stage in the life of a tire.

After more than four years of corresponding, visiting, writing, and editing, your editor senses that the nondestructive testing art is on the verge of bringing all the loose ends together into a package that will be of great value to the users and the producers. He does not have the solutions and only hopes that by asking the questions of you, the readers, that the needs, opportunities, and recommendations for concentrated effort will be explored and possibly answered - or even only enunciated for others to consider and research.

The preparation of the Third Symposium spanned two administrations of the Akron Rubber Group and it would be inadvisable to list the many fine people of the Group who assisted our effort lest someone be unintentionally omitted. The Akron Rubber Group was not a figurehead host. Their members gave outstanding support in many specific areas and our deep appreciation is expressed to them all.

Paul E. J. Vogel

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CHAPTER I - WELCOME TO AKRON

G. Robert Moore
Chairman, Akron Rubber Group
Harwick Chemical Corporation
Akron, Ohio

Ladies and gentlemen, on behalf of the Akron Rubber Group and the city of Akron, I welcome you to the Third Symposium on Nondestructive Testing of Tires. As many of you know, Akron wasn't always the rubber capital of the world. As a matter of fact, several other industries have been renowned here in Akron. The milling industry started out in the early 1820's and the reaper industry was prominent here in Akron in the early 20's and 30's and then moved westward. The rubber industry was founded here in 1870 by Benjamin Franklin Goodrich. He started out in small hose and similar rubber type materials. There are other prominent names that sprang up around the end of the century, names like Diamond, Miller, Firestone, Sieberling, Goodyear, and Star. Some of these you may remember; others are still prominent here in town.

Quite naturally, then, since Akron is the rubber capital of the world, the largest assembly of rubber technology is also here, and has banded together to form what we know today as the Akron Rubber Group. Our first Group meeting was in February of 1928, and has grown consistently with the rubber industry until today we have over 2,000 members. We have followed basically the same meeting format for many years. We have three technical meetings a year: one in the fall, generally in October; one in the winter, near the end of January; and one in the spring. We also have other types of outings for our general membership. We have a family night in the fall which is a sports type of evening, where we invite the family to go to the Coliseum to a hockey or basketball game. In the winter, we have our scholarship dance. This year it's going to be held around Valentine's Day at the Firestone Country Club. During the summer, we hold what we call the "world's largest golfout" at the Firestone Country Club. All members and guests of the Akron Rubber Group are invited and usually over 600 golfers participate.

The Akron Rubber Group is also somewhat philanthropic in nature and does maintain a nonprofit posture. We sponsor five scholarship students. Each of these deserving students must maintain a 3.0 overall average in their scientific or engineering field of endeavor. In addition, we hold a technical lecture series which consists of 10 or 12 lectures throughout the year. This year we started in January and will run through to about the middle of March, holding it on a Monday evening at Knight Hall at Akron University. These lectures are generally attended by about 9,400 people, and they are very technical in nature. I would like to invite all of you to attend our Annual Winter Technical Meeting, which is this Friday. It starts at 2:00 p.m. and admission is by membership to the Akron Rubber Group. If any of you are not members of the Akron Rubber Group, the membership tickets will be available at the door. We will have two technical symposia which will run simultaneously. One will be on rubber processing and the second is on "New Flexible Elastomers for Automotive Filler Panels and Facia." This is something completely new as far as the Akron Rubber Group is concerned. I would like to encourage all of you to attend if you so desire.

If any of you are looking for something to do here in the evenings, I would recommend the concerts and the ballets at the E. J. Commerce Performing Arts Hall. Also, Akron is renowned for its restaurants, and I can recommend several.

If you have any questions, or if there's anything at all that we in the Akron Rubber Group can do for you, don't hesitate to ask. Again, I want to welcome you and thank you for having me as your guest.

OPENING REMARKS

LTC Edward E. Chick
Army Materials and Mechanics Research Center
Watertown, Massachusetts

It is a pleasure for me to be here with you this morning to participate in the Third Symposium on Nondestructive Testing of Tires. First, I'd like to thank each of you for being here, thank the authors of papers you are about to hear, and the Akron Rubber Group for the support they have given in planning this meeting. We at the Army Materials and Mechanics Research Center are very pleased to be able to participate in this symposium and we believe it appropriate that the Army as well as the Materials Research Center do this because we are a pretty sizeable customer of the tire industry. The research and development community of the Army must, therefore, be intimately involved in the tire business. We believe that the Army's research community, which contains the Army Tank/Automotive Command's laboratories as well as our own, have made valuable contributions to the overall field of nondestructive testing of tires, and we know that the NDT Information Analysis Agency at our Center has been of service to you. I have reviewed the abstracts of the papers to be presented and also the previous symposia Proceedings. I was gratified to see that there are very obvious advancements in the techniques involved with the testing of tires, including the reliability of the procuct as well as apparent reductions in the cost. Cost reduction, of course, is the name of the game and it is vital that we continue making major progress along these lines. In order to do this, of course, requires additional investment in time and resources. To save money, we have to spend money. Each of us can only hope to attain what the Army sometimes refers to as "the biggest bang for the buck."

I came to my present assignment from the Army's European Research Office where I was fortunate enough to be able to travel around and visit various university, industrial, and nonprofit research organizations, and I did have a part to play in some of the nondestructive testing activities including the International Research and Development Corporation's research efforts in their laser speckle pattern technique. So I am familiar with the work that you people are doing.

I hope that you enjoy the symposium and that it will be a rewarding professional experience for you. If there is anything either I or my staff can do for you, please let us know.

CHAPTER II - KEYNOTE ADDRESS

Richard S. Walker
Vice President and Editorial Director, RUBBER WORLD
Akron, Ohio

If we look at the record, tires are better than ever and an extremely important factor in the "good life" we lead and a key to the prosperity we all desire for the future. After the discovery of the wheel itself, the invention of the pneumatic tire was a necessity to permit the development of our current most important mode of transportation, the motor vehicle. I, for one, firmly believe that automobiles, trucks, busses, and off-the-road rubber tired vehicles will continue to play their vital role in our lives for the foreseeable future. Rail, water, and air transport are also important but would soon grind to a halt without the support of road transport.

Look what has happened in just my lifetime! When I was a boy, a trip from our home in central Massachusetts, down the Connecticut Valley and along Long Island Sound, to my grandparents home in Westchester County, NY, was a major trip. Essential equipment carried in the trunk included the jack, lug wrench, and spare tire but also needed were a tube patching kit, tire changing irons, an air pump, and pressure gage and probably spare tubes. Not to mention chains, monkey links, candles, and lap robes if it was to be a winter excursion.

The roads, of course, were far inferior to those we are accustomed to today. Rough and full of pot holes. The chances of making such a trip without tire failure were slim indeed. Snow tires and snowplow equipped highway trucks had not yet become common and chains were the order of the day during snow periods. Broken chains also took their toll and caused punctures in many cases. Service stations to repair or replace tires were few and far between so the burden of keeping four good tires on the road fell on the motorist himself. The foresighted traveler had at least one, and probably more, spare tires with tubes mounted on rims and ready to go. If not, the tire had to be taken off the rim, a new tube inserted or the old tube patched and the assembly put back together followed by the exercise of pumping it back up by hand.

Today, only the jack, lug wrench, and spare tire remain. Even these are seldom used and probably they also will be obsolete as the run-flat or self-sealing tires reach maturity and reduce the normal complement of a car to four tires from the present five. As an aside, while it probably is not absolutely essential, I do recommend that the air pressure gage be retained on a vehicle and used periodically to insure proper inflation and thus maximum service of the present tires, good as they are.

At that time, we could expect five to 10,000 miles from a tire. In more recent times that value was pushed up to the 20 to 30,000 mile range and the introduction of the tubeless tire improved safety. Today we have the 40,000 mile radial tire which is also extremely durable. On a cost performance basis, allowing for inflation, tires are still a very good buy.

As an indication of relative tire values over the years, our sister magazine, Modern Tire Dealer, published a replica of a tire price book for 1920. In this listing there are basically two types of tires. Fabric reinforced and cord reinforced. The fabric tires were generally guaranteed for 5,000 miles and cost in a range from about $16.00 to as much as $50.00 or $60.00. Cord tires were generally guaranteed for 8,000 miles and prices ranged from about $30.00 up to over $100.00 in a few cases. Some of the fabric tires were rated for 7,500 miles particularly those described as Ford sizes. At least five of the cord tires were guaranteed for 10,000 miles and one manufacturer even stuck his neck out for 12,000 miles. As you can appreciate, however, at prices that don't seem out of line for today's tires they gave considerably less treadwear. And, we must remember, they required tubes which cost $3.00 to $10.00 additional when considering the total cost.

We are not here to discuss financial business particularly but these accomplishments have been made by an industry not famous for profitability. Wall Street and the investment community have consistantly rated the rubber industry below par due to low profits and below average return on investment. This does effect us as will be pointed out later.

Now! Why are we gathered here this week to discuss nondestructive testing of tires?

There are two important, major reasons why tire companies spend large sums of money for all types of testing.

The first is the most important and overriding reason for our existance. It is to provide the motoring public with the safest, longest lasting, and trouble-free tire possible consistant with

the quality level involved. This is basic and
should be uppermost in our minds at all times.

We sometimes lose sight of the forest because of
the trees and although our superiors' wishes and
the profit of the company must be considered, the
ultimate goal we must meet is for John and Jane
Public to be able to go to work, shopping, school,
vacation, or across country with minimal attention
to their tires ... and no trouble due to con-
struction or manufacture of those tires.

The other reason stems from the first and concerns
our obviously selfish desire to avoid warranty
replacements, scrap tires in production and, above
all, to avoid large scale recall problems. Any
of these problems are expensive and are nonpro-
ductive for both the consumer and the company.
Even if the customer is satisfied that fair treat-
ment was received in a replacement or allowance,
that person has been put through an extra period
of inconvenience. The company, also, loses money
on the deal. All of this, of course, must be
borne by the consumer in the form of higher prices.

Let's do some very elementary arithmetic. Produc-
tion of automobile and motorcycle tires in 1975
(not one of our better years) will exceed 150
million units. Using 260 working days this breaks
down to over 500 thousand units per day or 170
thousands units per shift in a three-shift day.
Assume an average wholesale price of $25.00 per
tire. On the basis of these assumptions, if just
one shift of all United States tire manufacturers
production were to be recalled, value of the
tires alone would be over $4 million. Add to
this the costs of the program and you can see
we are talking about big money.

We are all aware of the tremendous amount of
destructive testing carried out by tire companies.
There is still no alternate, as a final test, to
putting tires on a vehicle to find out how they
will perform. We cannot, however, test too many
production tires destructively and make money.
That has created the demand for nondestructive
tests which brings us together at this meeting.

The ultimate goal probably should be one or more
nondestructive tests on every tire produced.
This would provide the maximum assurance that
every tire shipped would perform satisfactorily
and keep warranty or recall returns to a minimum.

Saying this, and looking over this audience, I
see the suppliers of nondestructive testing equip-
ment gazing at the ceiling with big dollar signs
dancing in their eyes like proverbial sugar plums.
I'm sorry but again money, unfortunately, rears
its ugly head.

As with most situations, we must compromise. The
cost of nondestructive testing, or indeed all

testing, must be balanced against the value ob-
tained. Yes, warranty and recall programs cost
money. It makes no sense, however, to spend even
more money to reduce these programs to zero.
There has to be a balance which equals the lowest
net cost to the company.

We must do enough testing so that the quality
assurance level (the laws of chance to we gamblers)
will be of such a nature that we can be reasonably
sure that tires being shipped will be primarily
satisfactory thus minimizing any large warranty
costs but not so much that testing costs more
than any possible savings in warranty costs.

I cannot cell you where to draw the line. The
specific point will vary from company to company
and probably even from plant to plant within the
company. This is a condition which must be
analyzed carefully and determined by actual
experience as time goes on.

My point is that we must keep in mind that we can
provide valuable development information but the
greatest gain will come from providing production
people with a tool which will help to insure
quality and will help spot trouble spots. We
must do this, however, without adding excessive
costs in the process.

If a really good job is done with nondestructive
testing, furthermore, is should be possible to
spot and identify troublesome situations of either
a temporary or long-term nature so that these
problems can be rectified with a resulting in-
crease of productivity and quality as they are
eliminated. These two, productivity and quality,
are among our major goals to be met for improved
profitability.

Meeting these goals would be desirable under any
set of conditions but become extremely important
in the face of threats by government or consumer
groups forcing any real large scale recalls. As
pointed out before, recalls could cost a company
a great deal of money. Even the threat of a re-
call, however, could cause the expenditure of
considerable amounts of money in legal or related
costs even if the actual recall never takes place.

In spite of all best efforts, it is entirely pos-
sible that recalls will occur. In this event,
nondestructive testing could be invaluable. De-
pending upon the reason for the recall, it is
entirely possible that actually defective tires
could be identified and that those which are not
defective could be cleared and returned to in-
ventory for resale thus reducing considerably the
loss which the company might otherwise incur.

I don't think that it is necessarily bad for us
to have the government or consumer groups looking
over our shoulder and providing a stimulus for us

to do a better job. I am, however, somewhat at a loss to explain why the federal bureaucracy has singled out tires for such extreme regulation except that tires are highly visible and easily identifiable and once an item is involved in regulation large staffs and empires seem to be built by the bureaucrats. We are not perfect and as long as such monitoring is fair and not oppressive it can be a healthy condition making the public feel more secure. The safety record and the value delivered by tires today do not, in my mind, justify many of the regulative measures already in effect or being proposed.

What many of the regulators seem to forget is that we are in a very competitive industry even if it is somewhat limited in number of companies. Particularly here in Akron, if one company puts out a new line of tires it is not long before many of you here and other chemists and engineers of the competitive companies have a quality rating for that new line of tires. If it should turn out that this line is below average in the market place that fact will soon be known throughout the industry and the word gets back to the company involved. If necessary, additional design and development work gets cranked up on a crash basis as many of you present well know. This self appraisal is probably even more effective than any regulations in keeping us on our toes and insuring ever better products.

Meeting the needs of all these groups, the company, the motoring public, government regulation, and consumer organizations, however, is why we are gathered here today and why this conference is being held.

I am not an expert on nondestructive testing and I certainly am not going to try to suggest where or how any particular test might surpass another. Speakers to follow will cover the specifics in detail of holography, infrared, ultrasound, and X-ray. The working group reports on Thursday morning will undoubtedly add considerable new insight into each test method and what the benefits or drawbacks of each may be. There should be a place for each of the tests in the total scheme.

I would like, however, to make some general comments.

Those of you who are involved with the design, production, and sale of a particular piece of testing equipment are, I'm sure, firmly convinced of the superiority of your product and that it is the best on the market. This is as it should be. You owe it to yourselves and the industry, however, to present your facts, your tests and your potential as clearly and completely as possible so that a fair appraisal can be made by interested customers.

Those of you who will be involved in the evaluation and ultimate purchase of such units should keep an open mind in your deliberations to insure that you obtain for your company the best possible equipment for optimum results at the most reasonable costs.

While these suggestions may seem very elementary, I have seen so many cases where bias or personal prejudice color the decisions of an individual or department. Such decisions may or may not be in the best interests of the company for whom they work.

There is no question in my mind that, as things shake down, some companies will opt for certain tests and other companies will settle on another machine. Perhaps every company will have every type of test but this does seem somewhat unlikely in my mind. I certainly have no personal interest in any specific test and am only concerned that the equipment selected fits the needs of the company and helps to provide better tires for the future.

I wish to thank the organizers of this conference for asking me to take part and I wish you all, participants and guests, the greatest success here and in your future operations.

BANQUET ADDRESS

James C. Gilkey
Office of Standards Enforcement
National Highway Traffic Safety Administration
Washington, D.C.

It is indeed a pleasure for me to be with you today and participate in this Third Symposium on Nondestructive Testing of Tires. I would like to thank the sponsors of this symposium for their invitation.

As Mr. Vogel has indicated, I am with the National Highway Traffic Safety Administration, of the Department of Transportation. More specifically, I am in the Office of Standards Enforcement within the Motor Vehicle Programs area. It is the responsibility of our Office to enforce the Federal Motor Vehicle Safety Standards (FMVSS). We accomplish this mission by means of an in-depth physical test program and a comprehensive review of manufacturers' certification data. This evening I will be emphasizing the physical test program as I believe that will be of the most interest to you.

I will give you a general description of our overall test program and then describe in detail one of our most interesting individual programs. Time does not permit me to go into detail on all of our programs.

The subject which I will be discussing, compliance testing, may seem at first glance to be the exact opposite of the nondestructive type of testing which you have been and will be discussing. However, I believe that there is a definite tie-in of the two types of testing, even recognizing the primarily destructive nature of most existing compliance test methods. There is always the potential that some of our tests in the future may utilize nondestructive techniques either in lieu of or as an adjunct to present methods. As an example, the new ultrasonic testing procedure recently developed by DOT's Transportation Systems Center in Cambridge, Massachusetts, might well be used to pre-screen tires for indications of non-compliance with FMVSS No. 117, "Retreaded Pneumatic Tires - Passenger Cars." We presently check for compliance with the casing requirements of that Standard by peeling back the tread and making a visual examination of the cap-carcass interface. By using some type of nondestructive pre-screening technique, we might be better able to pin-point possible problem areas and thus be more efficient in our enforcement effort.

The basic approach used in our compliance test program is to selectively sample, on a random basis, new vehicles and items of motor vehicle equipment from the market place and subject them

to the tests specified in the standards. The tests are conducted at independent laboratories around the country. The number of laboratories used ranged from eight in the early days of our enforcement program to a high of 22 in Fiscal Year 1971. There were 17 in our most recent program, FY 1975. All known organizations having the capability to conduct each particular type of test are given the opportunity to bid and contracts are awarded on a competitive basis.

The high quality of work and degree of professional excellence that is present in the independent laboratories, and I am sure that many of you are associated with such organizations, is essential to a viable enforcement program. As you can recognize, it is imperative that tests be conducted strictly in accordance with the standards to ensure the validity of any failures which may occur. The effectiveness of our past enforcement efforts has been due, in no small measure, to the high caliber of work in the independent test laboratories.

We assign contract technical managers for each individual standard enforcement program. It is their responsibility to monitor the testing program by making periodic visits to the laboratory to ensure that correct procedures are followed and by reviewing all test results for accuracy. As further insurance against invalid results, we have an internal OSE Laboratory Audit Program. One of our engineers, who is highly skilled in instrumentation and calibration techniques, makes periodic reviews of the laboratory operating and calibration procedures. This engineer, who reports directly to the Director, OSE, helps to ensure that procedures and equipment are within prescribed guidelines.

If a failure occurs in our laboratory test we then initiate a comprehensive investigation on the item which failed. One of our first actions is to notify the manufacturer by phone of the failure. This permits him to immediately swing into action to check the adequacy of his product. We then follow up with a more formal document which we call the certification information request (CIR) letter, which may ask many questions but, most important, it requests the manufacturer's certification and surveillance test data. Parallel to this action we may conduct retests on the item and review other relevant data on the subject. After all of the information has been collected, our engineers conduct an intensive analysis of

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the data. We are particularly interested in the testing which the manufacturer has conducted both for original certification of the product and for in-process quality control. We review the procedures and equipment used as well as the results obtained. If there are differences in their results as compared to ours, we attempt to ascertain the reasons for such differences.

After completion of the analysis, we usually hold an informal technical meeting with representatives of the manufacturer and discuss any issues which are still unresolved. One of the primary considerations at such meetings is any recall action which the manufacturer may be considering. After the meeting, a decision is made, based on the technical data, as to whether there is a strong indication of noncompliance to the standard. If so, the case is forwarded to our Office of Chief Counsel for appropriate legal action. If not, the case is dropped.

The process which I have just described is the most simplified case. In many instances, there are several iterations of certain portions of the process. For example, there could be numerous letters to the manufacturer requesting additional data or numerous technical meetings.

As you might imagine, once the case reaches our Office of Chief Counsel, the procedures become more formal. In accordance with Public Law 89-563, the complete process requires that an Initial Determination of noncompliance must first be made, a public hearing is held to afford the manufacturer or any other interested party an opportunity to present their views and then a Final Determination is made.

There were 47 standards in effect in FY 1975 and 23 of these were included in our test program for that year. Some of the standards do not require an actual physical test to determine compliance - a visual examination is sufficient. For the standards which do require testing, we are forced by budget and manpower limitations to establish priorities and direct our efforts to those standards where we feel that our enforcement efforts will be of the greatest benefit. Our compliance testing budget was 3.4 million dollars in FY 1975. The OSE staff consisted of 45 people in FY 1975 with 34 of these being professional and the remainder being clerical support.

There are many standards for which tests were conducted as a part of the complete vehicle from the FY 1968 program through FY 1975. It should be noted that several of these standards require a full-scale crash test into a concrete barrier. In these crash tests we determine compliance with FMVSS No. 204, "Steering Column Displacement," FMVSS No. 212, "Windshield Mounting," and FMVSS No. 301, "Fuel Tank Integrity." Other standards

such as FMVSS No. 105, "Hydraulic Brake Systems," require a vehicle track test with instrumentation such as the fifth wheel.

A composite showing the compliance test program for equipment items from FY 1968 through FY 1975 includes items which are tested separately from the vehicle, sometimes referred to as "bench tests." These equipment tests are the ones with which I am most familiar as this is my particular area of responsibility.

Some examples of the types of equipment tests conducted are the whip test on brake hoses, cycling tests on seat belt retractors and these tests, with which I am sure that many of you are very familiar, bead unseat tests on tires and endurance and high speed wheel tests on tires. In 1975 there were 217 vehicle tests conducted with 18 failures for a failure rate of 8.3 percent. There were 2,859 equipment tests conducted with 102 failures for a failure rate of 3.6 percent.

I believe that gives you a fairly good picture of our overall test program and our investigative process. As an example, I would now like to go into more detail on one of our more recently initiated programs - motorcycle helmet testing.

Federal Motor Vehicle Safety Standard No. 218, "Motorcycle Helmets," became effective on March 1, 1974. Shortly thereafter we began planning our enforcement program for the standard. In a competitive procurement, a contract was awarded to the Southwest Research Institute in San Antonio, Texas, and compliance testing was started in September 1974.

The requirements of FMVSS No. 218 are impact attenuation, satisfactory labeling, retention system security, resistance to penetration, elimination of dangerous projections and satisfactory configuration.

On the equipment used to test to the impact requirement, the helmet is required to withstand drops of 72 inches onto a flat surface and 54.5 inches onto a hemispherical surface with accelerations of not more than 400 gs. Also, accelerations in excess of 200 gs shall not exceed a cumulative duration of 2.0 milliseconds and accelerations in excess of 150 gs shall not exceed a cumulative duration of 4.0 milliseconds. There is an instrumentation package used to monitor and record the results. The helmet is also required to resist penetration of a pointed instrument dropped from a height of 118.1 inches. Failure can be determined by examination of the aluminum headform on which the helmet is mounted.

The other requirements of the standard such as labeling, configuration, and elimination of dangerous projections do not require testing. Compliance can be determined by visual inspection.

In summary, I have attempted, this evening, to give you a general picture of the types of testing which are involved in the enforcement of the Federal Motor Vehicle Safety Standards. As you can see, it involves a rather wide spectrum of testing techniques, and some highly sophisticated equipment and instrumentation. However, it provides some very interesting technical challenges.

In the time remaining, I will be glad to answer any questions you may have.

CHAPTER III - GENERAL SESSION

THE ECONOMICS OF NDI IN RETREADING...AN INDEPENDENT SURVEY

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ABSTRACT

Exploring the economic justification
for NDI in the Retread Industry. Out-
lining the status of Retreading as a
market for NDI Systems. And presenting
the results of an independent survey
of the requirements and preferences
of Retreaders.

There are about 3600 individual retread shops in
the United States today. And they undoubtedly
comprise the largest potential market for non-
destructive inspection systems for tires. How-
ever, this market, like any other, must be under-
stood before it can be exploited. The wants and
needs of these 3600 highly independent retreaders
must be recognized before NDI of tires can
successfully make the transition from the labo-
ratory to the retread shop.

We have been intimately involved with many of
these shops and would like to briefly explore the
retread industry as a market for NDI with you.

Since retiring from full-time, active employment
in 1973, Kay Weir and I have been able to pursue
many developments in the tire industry that we
found interesting. The survey information I will
be presenting to you today grew out of our inter-
est in NDI for retread shops and our exploration
of retreader attitudes and needs through our
newsletter, THE ENDURING CALIFORNIA RETREADER.

First, an explanation of THE ENDURING CALIFORNIA
RETREADER, for it seems to need explanation.
Perhaps it is best described as the Free Press
of the retread industry. We write it as a per-
sonal communication to retread shop operators.
We give our opinions and observations about
whatever is on our minds; from equipment mainte-
nance tips and very personal and practical infor-
mation about things in retreading, to the state
of the economy and the latest "Wise Sayings."
It contains the kind of comments we would ex-
change if we could actually visit these people
every week or so.

The ECR is sent occasionally and irregularly to
whomever asks for it; and to some who don't. We

do not charge for it, and in no way does it com-
pete with the regular trade journals. It makes
no pretense at being unbiased.

The readership falls into two categories: retread
shop owners and foremen, those to whom we actually
address ourselves; and others who have asked to
receive it because they want to know what is going
on. Or at least our version of what is going on.

The survey about casing inspection and inspection
machines was included with ECR #11 and was mailed
October 31, 1975. It was kept short and rela-
tively simple to assure a large number of returns.
It was designed to implant as well as gather
information.

Survey Sample (Table I)

Most of the respondents are from California with
23% from other parts of the United States. All
are retreaders and one has a sideline, manufac-
turing new tire and retread equipment. In all,
they produce 8529 retreads per day. Of these
9.7% are truck retreads, 88.8% passenger retreads,
and 1.5% specialties (OTR, race, aircraft, etc.).

Comparing these figures to the best estimates of
retread shop production in the United States;
this survey covers about 1.2% of the shops in
the nation and 4.44% of the total national re-
tread production. It further breaks down to
5.57% of the total passenger car tire retread
production, 1.73% of the truck, and 1.6% of the
specialty retread production. The average shop
in our survey produces about three times the
national average.

Of those shops who operate passenger shops, 58%
are large, producing 101 or more retreads per day
day; 24% produce between 41 and 100, and 18%
produce 40 or less tires per day.

Forty-five percent of the shops do only passenger
car sizes, 38% do both truck and passenger sizes,
and 17% are exclusively truck tire treaders.

Most of the respondents who retread truck tires
have medium sized operations, doing between 11
and 50 truck tires per day; 45% are in this
category, 32% do 10 or less and only 23% are
large truck operations doing 51 or more truck
treads each day.

Twenty percent report an additional specailty.
And 23% of all the responding shops use some
precure system.

Radial Production

Of the shops doing passenger tires 42% report
doing some radials; 68% of the truck shops do
radials. However, of the total production reported
in this survey, only 3.74% of the passenger and
14.5% of the truck treads are radials.

Inspection Time

Most of the passenger shops report taking 1 to 3
minutes for casing inspection with the range of
reports from 1 to 10 minutes per tire. Truck
shops generally report taking 3 to 5 minutes with
the range from 2 to 10 minutes. Twenty percent
of the truck shops indicate that they use higher
inspection standards for their precure systems
than for their hot treads.

You must note from this information that there is
no such thing as a standard retread shop. Their
operations are many and varied.

Adjustment Rates (Line 4)

Reported adjustment rates range from 1/2 to 12%
for passenger and 1/4 to 13% for truck. The term
"adjustment" means something different to each
person using or hearing it. For my purposes, I
label as an "adjustment," any casing that has
had a new tread applied to it and is found unfit
for service anytime during the expected life of
that new tread. This includes mold blows and
other in-shop failures as well as rapid tread
wear, road hazards and policy adjustments. For
some retreaders, an adjustment is whatever he is
coerced into replacing by a screaming customer and
under threat of great bodily harm.

Correlating the reported adjustment rates with the
production figures from this survey, I find the
adjustment rate for passenger retreads in the
United States to be probably 6.49%. And the
truck retread adjustment rate to be around 3.54%.
These figures compare closely with what I actu-
ally see in the field.

Casing Failures (Line 5)

Information from the survey indicates that over
60% of retread adjustments are caused by casing
failures. My experience indicates this may be
on the low side. These are failures that are
caused by problems within the casings that the
retreader, with the present state-of-the-art, can
not detect before the casing is retreaded. That,
of course, is why I am here today.

Our figures indicate that 4.1% of all the passen-
ger retreads and 2.16% of all the truck retreads

produced fail because of casing defects. That
is about 1.6 million casing defect related fail-
ures per year or 6600 failures per working day.
More emphatically, casing failures are a
$17,000,000 a year problem!

Retreaders' Attitude

Retreaders are unable to control their adjustment
rate below a certain point. And I'd like to tell
you why. For many years the art of retreading
has been developed to the point where a new tread
could reasonably be expected to stay on a used
casing. But remember, retreading is a recycling
industry that requires a used product for its
prime raw material. This used product has often
been laced with "bombs" over which the treader
has had no control. Some of the "bombs" are in
the design and material changes that new tire
manufacturers initiate and send out into the
market. Let me list a few and you'll understand:

    1. The S2 and S3 tires of WW II which were
virtually unretreadable.
    2. The Air Ride tires of the late 40's.
    3. The conversion to Rayon.
    4. Nylon tires that grew and grew and flat-
spotted.
    5. Tubeless tires with their separations.
    6. Puncture sealing tubeless tires with the
goo.
    7. The Butyl tire disaster.
    8. Two-ply tires.
    9. The glass-belted tires we are only now
learning to live with.
    10. The first generation of steel belted
radial passenger tires which we only pretend to
know how to cope with.

Other "bombs" are the result of use and misuse
during the first tread life.

In addition to these casing problems, retreaders
have had equipment and processes unloaded upon
them that were filled with promises and little
else. Cynics are made, not born. And there are
many cynics in the retread industry. Those of
you here today who are preparing to take your
systems to the retreader must be aware of this
cynicism. (Personally, as an old retreader, I
think a little paranoia is a healthy thing!)

Back to Today's Casing Problems (Table II)

When analyzing his adjustments, in addition to
the field testing, the retreader finds himself
doing for the new tire manufacturer, he becomes
aware of certain regularly occurring conditions
in his failed retreads. This section is directed
towards those observations.

This is where the retreader needs NDI. Those
conditions listed on this table become visible

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THESE ARE QUESTIONS ABOUT CASING INSPECTION AND INSPECTION MACHINES

((There is no need to sign this questionaire but you may if you wish.))

1 WHAT PART OF THE COUNTRY ARE YOU IN? SO CAL _63%_ REST OF CALIF _15%_.
WESTERN U.S. _12_ EASTERN U.S. _2½_ SOUTHERN U.S. _2½_ OTHER _5%_.

2 ARE YOU A: RETREADER _100%_ CASING DEALER _—_ OTHER(specify) _MFG -1_.

3 VOLUME OF CAPS PER DAY: Truck _9.7%_ Passenger _88.8_ OTR___ Industrial___.
Aircraft_____ Racing_____ Other(name) _1.5%_.

4 WHAT IS YOUR ADJUSTMENT RATE? (Total from all causes including inshop loss.)
Be Honest! Passenger _½ -12%_ Truck _0 -13%_. Other _6:_____.

5 HOW MANY OF THE ABOVE ARE CASING FAILURES? _6.49%_ ½ _2%_ 1/3 _9%_ _3.54%_ ½ _36%_ 2/3 _10%_ 3/4 _50%_

6 DO YOU RETREAD RADIALS? Passenger, Yes _42%_ No____. Truck, Yes _68%_ No_____.

7 IF SO, WHAT % OF YOUR TOTAL PRODUCTION IS RADIAL? Truck _14.5%_ Passenger _3.7%_

8 INSPECTION TIME PER TIRE (in minutes): Truck_____ Passenger_____ Other_____.

DOES THIS INCLUDE MINOR PATCHING? Yes___ No___.
25% Do Some. Precure.

9. IF YOU DO BOTH HOT & PRECURE, DO YOU USE THE SAME INSPECTION STANDARDS FOR
BOTH? Yes _80%_ No____. IF NOT, WHICH IS HIGHER? Hot____ Precure _20%_

TABLE I - - - - - WEIR 1976

10 WHEN ANALYSING YOUR ADJUSTMENTS, HAVE YOU COME ACCROSS THE FOLLOWING:

(This question is related to underlined casing failure only, NOT CAP LIFTS.
Casing failure must be considered anytime that you can see cord.)

		OFTEN	SOMETIMES	RARELY	NEVER
A	STEEL BELT RUSTING...	18% 49% 31%		31%	5%
B	CORD FRACTURES.......	33 69. 36		20	2%
C	BEADS BENT..........	13 23 10		41	23
D	CASING POROSITY......	10 38 28		41	5
E	BEAD FRACTURES.......	13 23 10		44	18
F	BELTS BROKEN........	56 84 28		2	2
G	INTRA-PLY SEPS.......	67 95 28		0	0
H.	EXPOSED CORD (top ply)	28 51 23		31	2

TABLE II - - - - - WEIR 1976

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only after a retread has failed. Yet we know that some of these conditions are present in the casing when it is inspected and passed. Currently, casing inspection for retreading is a beauty contest only. I have clients using prime #1 casings exclusively with 7% casing failures while others have 3% casing failures using #2s and 3s.

With our present grading system, the difference between grades is more in the surface condition of the casing, not in its basic integrity. The inspector looks for exposed cords, oxidation, torn beads, nail holes, broken belts, breaks, and separations. But what can he really find? Not much when it comes to the broken belts, breaks, separations, and other conditions listed on this table. As of today, he can be sure that at least 4% of all the passenger casings and 2% of all the truck casings that he inspects will fail because of problems within the casing that he can't see. He knows he is retreading bad casings but he has no way of identifying them.

The responses to the "often" and "sometimes" columns in question 10 were combined to find the most observed conditions in failed retreads. Heading the list by far was intra-ply seps. Not a single respondent indicated that he rarely or never saw intra-ply seps. Next in order were broken belts, cord fractures (breaks), top-ply seps, and steel belt rusting at 49%. Since radial passenger production is only 3.75% of the total, and many of these are fabric belts, the impact of this problem has not been felt by most retreaders.

As a personal note, I made cuts of over 100 steel belted passenger radial casings about a year ago. I found belt rusting in every tire and belt edge separation in more than 75%. The only casings without belt edge separations were those under 175 cross section.

NDI Market Potential

Some clue to the market potential for NDI in retreading can be found in the cost of casing related failures. Truck treaders indicate that 2.16% of all the tires they retread fail because of casing defects they can not find with their current inspection systems. This is over 1/4 million annually. Most truck retreads are on the users' casing which is not normally guaranteed. Therefore, I figure the average truck adjustment at $20 per tire. This gives us a $5,200,000 annual loss.

Passenger treaders indicate that 4.1% of their product will fail from undetected casing defects. That is almost 1.4 million units per year. With a production cost of $7, plus $1.50 for a casing, we have a whopping $11.8 million annual loss.

Conservatively then, since these figures do not include truck casing replacement costs, NDI systems and equipment designers can help the retread industry save $17,000,000 and 5 million gallons of oil each year. Effective NDI systems can reduce the total adjustment to less than 1-1/2% for truck and 2-1/2% for passenger. This would greatly increase the stature and profitability of this re-emerging industry.

Table III

The survey asked in several ways what retreaders would be willing to pay for a machine or system that would reduce their casing caused adjustments by 90%. Question #20 asked for this information directly. The range of choices was from $2,500 to $50,000. The average of responses was for a machine that cost $7,500.

Additionally (line 17) we asked what they would be willing to pay on a per tire basis. Truckers indicate they are willing to pay from 50¢ to $2.00 per tire for 90% accurate NDI. The average response being $1.15 per tire. Personally, I don't feel that they will really part with that much money.

Passenger treaders say they are willing to pay from 10¢ to $1.00 per casing with an average of 29¢. I feel that figure is more realistic and in line with what their adjustments actually cost them. Casing failure adjustments cost the passenger retread industry just under 35¢ per unit. Truck casing problems cost about 43¢ per tire if the casing is not included. If it were added, that figure would nearly double to 85¢ for every truck tire retreaded in the United States.

Most retreaders indicate they would like to have the machine pay for itself in three years, and that they would rather buy than lease the equipment; 92% thought such a machine would be valuable to them and 67% think it could be an advertising advantage. Half the treaders think their product liability insurance costs would not be reduced. Comments returned with this question are further indications of retreaders' cynicism. (Some of these comments are included in the appendix.)

Fifty-one percent of these treaders say they are willing to buy pre-screened casings at a premium price. This could be one way for small shops to make use of an expensive system should that be the result of your development.

Another indication of the retreader's willingness to pay for equipment that meets his need and that he can use, is AMF's Orbitread. It requires a minimum five year lease with some $4000 for down payment and installation plus 4¢ per pound of rubber used. A 100 tire per day passenger shop pays about $40,000 over those five

Any Non Destructive Inspection Machine would be used in addition to your normal inspection process. It is not a substitute but an additional tool. These machines vary in their approach but usually indicate in one way or another, casing integrity. Some indicate actual separations & Other anomalies while other machines indicate the casing's potential for failure.

11 WOULD A MACHINE THAT WOULD REDUCE YOUR CASING ADJUSTMENTS BY 90% BE VALUABLE TO YOU? Yes _92%_ No _5%_ ?3%

12 WOULD YOU EXPECT AN ADVERTISING ADVANTAGE IN HAVING SUCH A ?8% MACHINE? Yes _67%_ No _25%_ .

13 WOULD YOU EXPECT THIS MACHINE TO REDUCE YOUR PRODUCT LIABILITY INSURANCE PREMIUMS? Yes _37%_ No _50%_ .

14 DO YOU THINK IT WOULD PAY YOU TO HAVE A MACHINE LIKE THIS? ?27% Yes _68%_ No _5%_ .

15 WOULD YOU BUY PRE-SCREENED CASINGS AT A PREMIUM PRICE? ?11% Yes _51%_ No _38%_ .

16 WHAT KIND OF PERFORMANCE PROOF WOULD YOU REQUIRE BEFORE INSTALLING SUCH A "CASING INTEGRITY MACHINE"? _____ .

17 HOW MUCH PER CASING WOULD YOU BE WILLING TO PAY FOR SUCH A MACHINE? (Be Honest!) Truck: 50¢ _39%_ $1 _25%_ $2 _36%_ $5 ___
Passenger: 10¢ _31%_ 25¢ _38%_ 50¢ _12%_ $1 _7%_ Other ?_12%_ .

18 WOULD YOU WANT THE MACHINE TO PAY FOR ITSELF IN 3 YEARS _63%_, 4 YEARS _7%_, 5 YEARS _16%_.

19 WOULD YOU PREFER TO LEASE OR BUY? Lease _22%_ Buy _63%_ 15%

20 WOULD YOU PAY $5,000 _26%_ $7,5000 _24%_ $10,000 _18%_ $20,000 _5%_ $50,000 _5%_ . 2500 5%.

21 FROM WHAT YOU MAY KNOW ABOUT THESE MACHINES, WHICH SYSTEM DO YOU PREFER AT THIS TIME? (Number them 1,2,3,4, in order of your preference.)
_1%_ X-RAY, XEROGRAPHY, NEUTROGRAPHY. (This type, in effect, looks through the casing. It may or may not find seps. It generally is better for finding cord anomalies.)
_13_ INFRA-RED & HEAT SENSING. (This is generally a test wheel type operation. It may locate seps & gross cord problems.)
_85_ SONIC, PULSE-ECHO, THROUGH TRANSMITION, ACUSTIC EMISSION. (These may be able to discern between various casing & cord bonds, indicating casing fatigue & integrity. May or may not pick up seps.)
_1%_ LASER HOLOGRAPHY. (Picks up distortion & stress in casing in photographs. May or may not indicate seps.)

22 HAVE YOU EVER USED ONE OF THE ABOVE SYSTEMS? Yes _10%_ No ____ .

If yes, what was your experience? _____ .

TABLE III - - - WEIR 1976

years. That is a lot of money and there are a lot of Orbitreads in use.

Survey Data

Table 4 has some of the data upon which this report is based. These are real figures from real shops, shops that will be buying NDI equipment. The columns indicate shop volume, adjustments (in actual numbers of tires per day) what the shop is willing to pay for NDI, and the actual cost of casing adjustments for that shop (using his figures).

Let's look at shop #7. He produces 10 truck and 125 passenger treads per day. His total adjustments are 0.5 truck per day and 6.25 passenger per day. His casing failures are 0.375 per day for truck and 4.69 for passenger. He says he will pay 25¢ or $7800 per year for NDI for his passenger tires. He chose not to comment on an outright purchase price for an NDI system. However, casing failures actually cost him $1875 a year for truck and $9970 for passenger. Casing failures are costing him almost $12,000 a year.

Shop #27 produces 120 truck and 250 passenger retreads a day. He has 4.8 truck and 10 passenger adjustments per day. And 3.6 truck and 7.5 passenger casing failures per day. He agrees to pay 50¢ for truck and 25¢ for passenger NDI. That equals $15,000 a year for truck and $15,625 for passenger. For outright purchase, he considers $10,000 to be the right price. However, his actual casing failure costs are $18,000 for truck and $15,900 for passenger retreading each year.

For another view of the cost of inadequate casing inspection, the "average" shop in the United States produces 38 passenger tires and 13 truck tires per day. For this modest sized shop, casing failures cost $4700 each year.

TABLE IV — DAILY PRODUCTION & ADJUSTMENT FIGURES / ADJUSTMENT COSTS — RESPONDENTS WILLING TO PAY

line #	Total Production T	Total Production P	Adjustments (all causes) T	Adjustments P	Casing Failures T	Casing Failures F	Per Casing $ T	Per Casing $ P	Per Year $ T	Per Year $ P	FOB Machine Purchase $	Actual Cost of Casing Adjustments T	Actual Cost P
1		150		6.00		3.00							6,375
2	10	150	0.50	7.50	0.25	3.75					5,000	1,250	7,970
3		140		9.80		6.53		.10		3,500	10,000		13,875
4	7		0.21		0.15		2.00		3,500		NO	750	
5	50		5.00		1.25		.50		6,250		2,500	6,250	
6		60		6.00		3.00		.25		3,750	----		6,375
7	10	125	0.50	6.25	0.375	4.69		.25		7,800		1,875	9,970
8		350		14.00		10.50		?					22,300
9	5	25	0.25	1.25	0.125	0.63	.50	.10	625	625	5,000	625	1,340
10		350		35.00		17.50		.25		21,875	50,000		37,200
11	30		0.90		0.45		2.00		15,000		5,000	2,250	
12	100	600	2.00	72.00	1.00	36.00		?			?	5,000	76,500
13	100		2.30		1.73						5,000	8,650	
14	70	100	1.40	0.50	0.70	0.25	1.00	.10	17,500	2,500	7,500	3,500	530
15	70	20	4.20	1.20	2.80	0.80	2.00	.50	35,000	2,500	?	14,000	2,500
16		150		7.50		5.63		1.00		37,500	7,500		10,000
17	75	100	0.13	3.00	0.06	1.50	2.00	.50	12,500	12,500	10,000	300	3,200
18	25		0.40		0.30		1.00		6,250		5,000	1,500	
19		7		0.14		0.10	1.00			1,750	7,500		212
20		100		6.00		4.00		.25		6,250	7,500		8,500
21		360		18.00		9.00		.10		9,000	5,000		19,125
22	10	20	0.50	2.00	0.37	1.50	2.00	.25	5,000	1,250	NO	1,850	3,200
23	10	40	0.10	0.40	0.05	0.20	?	?			?	250	425
24	10		0.40		0.20							1,000	
25		100		2.00		1.50		.25		6,250			3,200
26	24	85	0.06	0.42	0.02	0.15	1.00		6,000			250	320
27	120	250	4.80	10.00	3.60	7.50	.50	.25	15,000	15,625	10,000	18,000	15,900
28		350		42.00		21.00					5,000		44,625
29		600		27.00		13.50		.50		75,000			28,700
30		675		54.00		40.50		.25		42,200	10,000		86,000
31		160		16.80		12.60		.25		10,000	20,000		26,775
32	30	20	1.35	0.80	1.22	0.72	.50	.10	3,750	500	7,500	6,100	1,530
33	10	450	1.30	27.00	0.87	18.00		.25		28,125	2,500	4,350	28,250
34		60		3.30		2.48							5,270
35	50		1.50		1.13		.50		6,250		5,000	5,650	
36		300		19.50		14.63					5,000		31,100
37	30	75	0.30	2.25	0.23	1.69	.50	.10	3,750	1,875	7,500	1,150	3,600
38		300		24.00		18.00		.10		7,500	10,000		38,250
39	20	200	1.00	15.00	0.75	11.25						3,750	23,900
40	12	1100	0.24	50.60	0.18	37.95		.10		27,500	7,500	900	80,600

Desired Features (Table V)

No matter how good you think your NDI system is, I believe you must listen to what the retreader is asking for. He, after all, is the one who is going to pay for it. And he, most of all, is the one who knows what the requirements of his shop operation are.

We found that speed of operation is the most desired feature for any NDI machine or system. I think that speed of operation should include not only through-put but also real or near real-time operation. Next desired is simplified operation. Tied for third, and we were surprised, (we'd expected they would be first and second) were cost and ease of operation.

The least desired of the features we asked about was an oscilloscope. However, one respondent suggested that it would be great to dazzle his customers.

The nondestructive inspection of tires is a reality. It can be done. We are meeting here for these three days to discuss the many ways it can be done. And, though new methods are constantly being developed, a number of systems have matured to the point where it is time to consider their practical application in the field. As I pointed out in my opening comments, retreading is probably the biggest field for these systems.

Retreaders need NDI. Retreaders can pay for NDI. And those of you here with laboratory matured NDI systems need retreaders so that you can now make your research pay for itself. If you recognize the retreader's needs; if you listen to what he has to say to you; if you accept and work around his limitations, economic and otherwise; you can establish a mutually rewarding relationship. You will have a good customer for your product. He will buy and use your machines.

I'd like to close with a comment from one of the respondents to our questionnaire. "You can only add so many steps to the process, each of which costs money, before a retread costs as much as a new tire....Your machine would have to be simple enough for the "typical retreader" to use without the boss having to take over the inspector's job. There have been enough good ideas that didn't work sold to the retreading industry to last a lifetime."

QUESTIONS AND ANSWERS

Q: I am interested to know how the retreader goes about limiting an age for which he will no longer retread?
A: Certain limitations in passenger tires have been set upon us by the type of tire that is being accepted. We can only retread DOT-approved tires which are certain sizes. From 1968 on, I believe.

23 FROM WHAT YOU KNOW ABOUT THE LIMITATIONS OF NDI MACHINES, INDICATE THE IMPORTANCE TO YOU OF THE FOLLOWING FACTORS:

		NOT IMPORTANT	MAYBE	VERY IMPORTANT
A	SIZE OF MACHINE............	11%	39%	35%
B	COST OF MACHINE............	0	15	81
C	SPEED OF OPERATION.........	0	8	88
D	EASE OF OPERATION..........	3	12	81
	TEST READOUT:			
E	DETAILED INFORMATION....	27	35	15
F	SIMPLIFIED INFORMATION..	0	3	85
G	OSCILLOSCOPE............	42	23	12
H	DIGITAL READ OUT........	15	42	15
I	LIGHTS (go, no-go)......	3	31	58
J	PRINTED RECORD OF TEST..	23	31	19

24 WOULD YOU BE WILLING TO KEEP THE ROCORDS, ETC., NECESSARY FOR PARTICIPATING IN FIELD TESTS OF SUCH A MACHINE? Yes 100% No____.

TABLE V - - - - - WEIR 1976

19

NDI MACHINES IN RETREADING, SURVEY DATA

James D. Weir
~ Inc.

1000 PROSPECT CHINO CITY, CALIF
94100   (1) 8/000-0000

SHOP PRODUCTION.... | Of those shops reporting:
35% do both truck and passenger.
17% do only truck
45% do only passenger (may have small specialty)
20% have additional specialty (OTR, race, aircraft, ind.)
82% produce at least some passenger. (adj rate 6.5%)
55% produce at least some truck. (adj. rate 3.5%)

SHOP VOLUME........ | 18% Small Passenger (40 or less/day)(adj rate 4.66%)
24% Med Passenger (41 to 100/day)(adj rate 3.8%)
58% Large Passenger (101 or more /day)(adj rate 6.76%)

32% Small truck (10 or less/day)
45% Med Truck (11 to 50/day)
23% Large truck (51 or more)

Total volume of survey = 4.48% of all U.S. retread production.
~ Truck. 1.715% vs. ___ Pass 6.57 % 1.6% Spec.
25% use some precure system.

INSPECTION TIME.... | **TRUCK**
(per tire)
2-3 minutes with patching...-......16%
2-3 minutes without patch........26%

4-5 minutes with patching.....16%
4-5 minutes with-out patch....21%
6-10 minutes with patching....16%
6-10 minutes without patch.... 5%

PASSENGER
1 minute or less with repairs......11%
1 minute or less without repairs...26%
1½-3 minutes with repairs.....22%
1½-3 minutes without repairs..26%

3½-6 minutes with repairs....7%
3½-6 minutes without repairs..4%

10 minutes without repairs....4%

14.5% of truck retread production is radial.
3.74% of passenger retread production is radial.

42% of the passenger shops do some radials (from 2 to 30%)
68% of the truck shops do some radials. (from 5 to 20%)

25% of Pass. shops reporting doing radials do less than 10/d
25% of Truck shops reporting doing radials do less than 2/da

TRUCK..... | Adjustment rate: 3.53%
61.3% of these adjustments are reported to be caused
by casing failures.
2.16% of truck retreads will fail because of casings.
(256,000 truck retread failures)
($5,200,000 per year cost)
($20 average cost to produce a truck retread. Not
including casing.)
Truckers are adjusting about 1000 retreads/day because
of inadequate casing inspection systems.

PASSENGER..... | Adjustment rate: 6.49%
63.1% of these adjustments are reported to be caused
by casing failures.
4.1% of passenger retreads will fail because of casings.
(1,400,000 failures/ year)
($11,800,00 per year cost)
($7 production cost and $1.50 casing)
Passenger treaders are adjusting about 5,600 retreads/day
because of inadequate casing inspection systems.

If casings could be guaranteed perfect, retreaders'
adjustment rates could be reduced to 1.37% for truck
and 2.39% for passenger.

COMMENTS FROM SURVEY SHEETS

QUESTION NUMBER

10-C-2 (Beads Bent) Answer: Sometimes. "Get more stripped beads."

#11 WOULD A MACHINE BE VALUABLE?.."Depending on cost on acquiring
and operation.

#12 WOULD YOU EXPECT ADVERTISING ADVANTAGE?.."Yes, wholesale
only. No point of sale benefit."

#13 REDUCE INSURANCE PREMIUMS?..."No. Did 55 MPH lower your
insurance rates?"

"Doubtfull. Most ins. co. do not reduce business."

#15 BUY PRESCREENED CASINGS?..."No. Who would do it? How
would you be sure?"

"Yes if they are waranteed."

"No. Not trusting is my problem."

#16 PERFORMANCE PROOF REQUIRED..."Installation & 90 days usage
of this machine."

"Time tested"

"100% better than what we now use."

"Sell with take back or lease with escape clause."

"Prefer in shop"

"A well tested machine with retreads on vehicles
extended period of time."

"Testing"

"Much proof"

"Reduced insurance based upon proven reduced ad-
justments."

"I'm from Missouri (figuratively)."

"Inventory of supplier."

"Government approval or constant use approval."

"(1) Lab results (2) In-use test period (3) Speed
of machine."

"Infield testing of machine"

"DOT Approval"

"better than 95% accuracy."

"1 year testing in shop"

"Cross checks with pull tests and destruct testing."

"Considerable reduction in ply separations"

"6 mo to 1 yrs use by a "custom" capper. (one who
caps customers cassings retail)

#19 LEASE OR BUY?,..."Depends on cost. AMP had good idea, lease
& give service on complex machine."

"Either or. Dependent upon amassed value of
machine after 90 day evaluation."

#21 WHICH SYSTEMS PREFER AT THIS TIME?
Don't know
Not Knowledgable
Don't know enough to choose

#22 USED MACHINE BEFORE? Yes. "Good but needed improvement"

"Cost = NA, Result questionable"

#24 WILLING TO FIELD TEST? "Yes. Depends on how much trouble
it would be."

#25 COMMENTS: "Good job, Jim."

"Those ((questions)) that are not answered would be guess-
work. This area is new and no previous thought given to
same."

"Am fearful of the price and time required per tire."

"How sofistiyated will the retread industry become before
the user "industry" (truck, off road) is made aware of
those specific new tires (by name and grade) that they
purchase(d) are prone to (or more prone to) failure then
another make and grade offered?.........By whom shall this
information come to the user?"

"Build it, test it, prove it, I'll buy it & sell it."

"Adjustment ratio abnormally high due to: 1. Former shop
manager not using proper systems, 2. Experiments in A-?
kettle retreading that did not work out. Prior years we
used a 4% of shop selling price to our store (about 30% on
Goodyear list price) and put into retread reserve account.
Adjustment credits issued to customer offset this account.
At end of year we would kick balance into profit. In the
past we allways had a balance leaving 2½-3% true adjustment.
Not this year. Good shop practice there should result in
adj % of about 2-2½%. Machine could possibly improve 1%.
Save maybe $4,500 per year less the cost of operating the
thing. How much is it worth ???"

"Major determining factor will have to be price. May
require group use of machine in geographic area."

"I plan to take on pre-cure in next year. I have no
experience with radial capping....I hope pre-cure will
include radial capping (trk & pass)."

"The machine produced by the Fed government & introduced
at Louisville, Ky last spring may well be a beginning to
the answer. Do not believe it is total ans. yet. Perhaps
that combined with a floarascope such as older Doctors had
might be a direction to follow."

"For the few caps we do this machine would not be economical."

"You can only add so many steps to the process, each of
which costs money, before a retread costs as much as a new
tire. We sent out $5,000 casing conditioner back, we junked
our $5,000 Fuller automatic venter. In our area most people
with automatic presses have sold them or gone broke. Your
machine would have to be simple enough for the "typical
retreader" to use without the Boss having to take over the
Inspector's job. I went to an auction in Texas 6 months
back and saw an IRI extruder builder sell for $800.00 and
an IRI press for $200.00. There has been enough good ideas
sold to the retreading industry that didn't work to last
a lifetime."

SHORT DURATION TREAD WEAR MEASUREMENTS OF 7.00-16 LW (6 PR) MILITARY NDCC TIRES

Dieterich J. Schuring
Firestone Tire & Rubber Company
Central Research
Akron, Ohio

ABSTRACT

A series of wear tests using NDCC military 7.00-16 tires were performed on Calspan's Tire Research Facility (TIRF) with the objective to develop an efficient test methodology that would permit the determination of a tire's wear loss after only a few hours' run of normal severity. This required the development of an accurate electromechanical wear measuring device and of a short-duration wear run technique. After systematic elimination or reduction of all major sources of experimental errors, the influences of tire pressure, load, slip angle, and driving and braking torque on tread wear were investigated. The agreement between wear data measured on TIRF and corresponding data measured in road tests (Yuma Proving Ground) was satisfactory. Suggestions are made for a second-phase program.

INTRODUCTION

Wear resistance is one of the most important properties of pneumatic tires, not only because it determines a tire's useful life but also because it is related to its traction properties and, of course, to its safe use.

Four different techniques have been developed in the past for studying the wear properties of tires, all with some virtues, but none satisfactory. *Laboratory* tests of small tread samples are widely used to assess the influence of various tread compounds on tire wear resistance; they fail to reproduce the rather complicated tread motions in the contact area but, nevertheless, produce in short time valuable inputs for compound improvements. For predicting the actual wear life of a given tire, however, testing small tread samples is of little use.

Tire road tests, on the other hand, have the great advantage of exposing the tire (and not just a sample) to real-life conditions, if they are conducted under *normal* (non-accelerated) wear conditions. They reflect, in "natural" fashion, the many influences of driver, vehicle, roadway, traffic, environment, etc., on tire wear. Road tests are usually run with two types of tires -- test tires and control tires. By exposing both test and control tires simultaneously to the same set of (uncontrollable and often rapidly changing) service parameters, their influence can be reduced to a level of acceptable accuracy. To assess the attainable accuracy, consider the results of recent road tests (Figure 1). Two radial tires of the same brand were road tested on the same test course, 500 miles a day for 16 days. After completion of each daily run, the average reduction of groove depth was measured for each tire. The results indicate a large day-to-day fluctuation not only of the wear rate (Figure 1a), but also of the wear rate differences between the two tires (Figure 1b), due to unavoidable changes in weather, driver behavior, road conditions, and other uncontrollable factors. It is obvious that these large fluctuations necessitate rather long test distances (here, 8000 miles) with attendant long test times (here, 16 work days) and high costs.
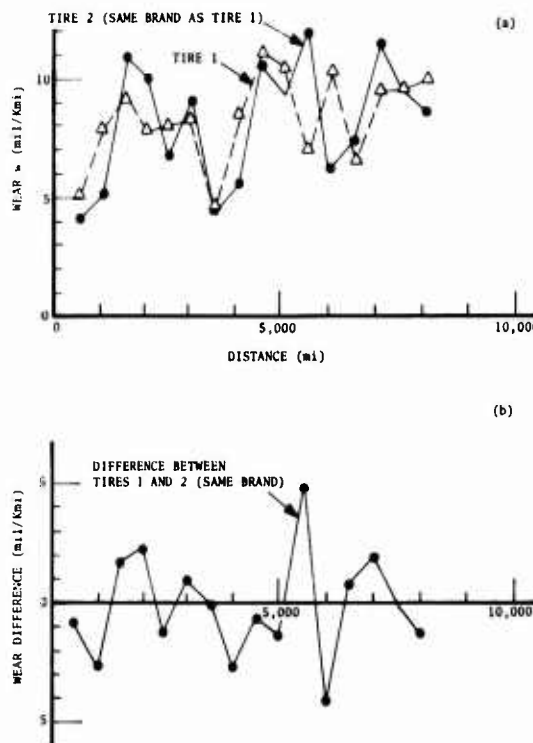
Figure 1. Results of road wear tests (from ref. 1).

Attempts to reduce the high cost of road testing under normal wear conditions have not yet been very successful. *Mathematical wear models* are in their infancy; at their present stage of development, their predictive power is very limited. Wear testing under severe wear conditions, so-called *"accelerated" wear*, another alternative, is not satisfactory either. Testing under severe conditions yields considerable wear after only a few hundred miles of tire travel and thus reduces test cost; but since test results failed to correlate well with results from normal wear testing (as we will see), the usefulness of accelerated wear testing is questionable.

Clearly, a (fifth) method is needed that would combine the advantages of controlled, short-term laboratory tests with the real-life wear conditions of road testing. Until recently, the road systems of laboratory tire testers were severely deficient; the surface was either curved (drums) and thus unable to reproduce the correct road geometry, or very short and/or of low speed (flat-bed test machines) and hence incapable of generating realistic wear conditions. With Calspan's Advanced Tire Research Facility (TIRF), however, these disadvantages were removed. TIRF features a flat road surface with a speed range up to 200 mph. Also, since all external wear parameters such as slip angle, load, and speed are tightly controlled, large data fluctuations -- the major obstacle to short-duration tests under normal wear conditions -- are avoided. Therefore, an opportunity was offered for the first time to test tires on an indoor facility such as TIRF or a similar (simpler) machine under realistic (i.e., not accelerated) wear conditions, at test durations much shorter than those necessary for road tests.

The following study is primarily concerned with the development of an efficient test methodology that would permit the measurement of a tire's wear loss after a few hours' run at normal severity with an accuracy of less than one mil (0.001 inch = 25-μm). Ultimately, the short duration indoor wear technique is expected to deliver low-cost wear data for wear cycles (varying speed, slip angle, load, camber angle, etc.) patterned after actual wear conditions. The following study is a first step toward that goal.

DEFINITION OF NORMAL WEAR

Tread wear is defined as the gradual loss of tread rubber through tire usage on the road. The loss of rubber can be expressed as loss of groove depth, or tire weight, or tire volume; or it can be characterized in terms of expected tread life. Here, wear is expressed as loss in tread depth in mil per kilomile (1 kmi = 1000 miles) traveled.

$$\text{wear} \quad w = \left\{ \frac{\text{loss in tread dpeth}}{\text{distance traveled}}, \frac{\text{mil}}{\text{kmi}} \right.$$

Since wear is closely related to tire slip, normal wear in city and highway driving can be assessed by an evaluation of the slip an automobile is encountering in normal driving. We performed such an evaluation using data of recent investigations by Veith [2] and Chiesa [3]. Veith made a survey of the longitudinal and lateral accelerations experienced by an automobile driven in cities, on rural roads, and on highways. From his data, we computed in an approximate way the distributions of slip angle and longitudinal slip, Figures 2 and 3. For city driving, the slip angle distribution shows two peaks. The first peak at the small value of the slip angle of 0.07 degree can be associated with the small steering corrections necessary to keep the car on a basically straight course. The second peak at about 1.3 degrees can be related to major directional changes (for instance, right angle turns). For interstate highway driving, a distinct peak shows at about 0.2 degree, presumably caused by correctional steer inputs at higher speeds. A very small peak is apparent at about one degree, perhaps produced by passing maneuvers. If we postulate that severe wear is associated with slip angle frequencies
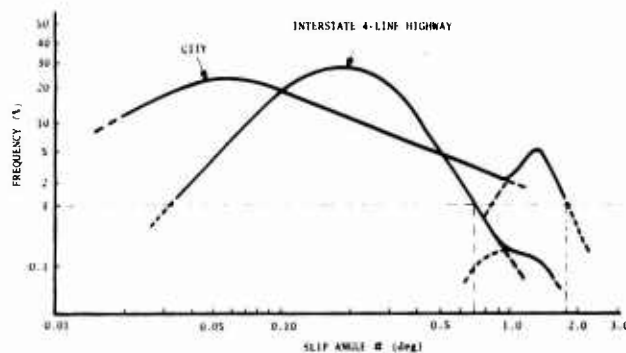
Figure 2. Slip-angle distribution of a passenger car for normal city and highway journey patterns (adapted from ref. 2).
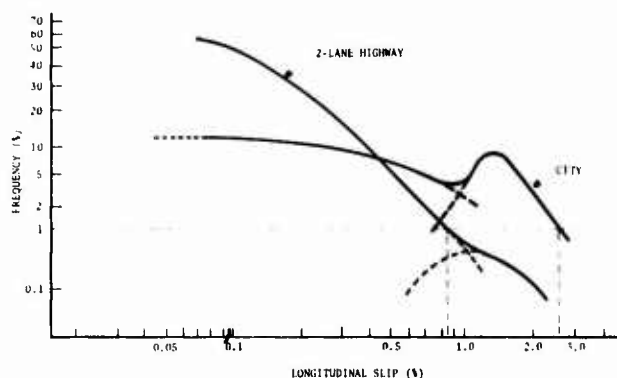
Figure 3. Longitudinal-slip distribution of a passenger car for normal city and highway journey patterns (adapted from ref. 2).

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smaller than one percent, then according to Figure 2 all slip angles smaller than 2 degrees must be considered causing normal wear.

The distributions of longitudinal slip (braking and driving) are similar to those of slip angle, Figure 3. If we postulate again the frequency of one percent as bounding the normal wear regime, all longitudinal slip values smaller than 2.5% are defined as causing normal wear.

In the light of these diagrams, then, normal wear takes place at slip angles less than 2 degrees and at longitudinal slip values less than 2.5%; wear occurring at larger values must be considered severe, i.e., outside the regime of normal driving conditions.

These conclusions are confirmed by test results presented by Chiesa and Ghilardi [3] who determined tire wear on roads of different driving severity. The driving severity was expressed in terms of the 99th percentile acceleration (lateral and longitudinal); if 99% of the accelerations experienced by the vehicle under given driving conditions were smaller than 0.1 g, the course was considered of low severity, with a wear rate of 7 mil/kmi; corresponding accelerations and wear rates for courses of medium and high severity were defined at 0.2 g (16 mil/kmi wear) and 0.4 g (70 mil/kmi wear), respectively. From Chiesa and Ghilardi's data, we estimated the 99th percentile slip angles and longitudinal slip values, Table 1. Again, normal wear under low and medium driving conditions occurs at slip angles below 2 degrees and at longitudinal slip values below 2.5 percent. Slip angles above 2 degrees and longitudinal slip values surpassing 2.5% are considered of high severity.

High severity and low severity driving appear to be associated with different wear mechanisms. Many wear tests revealed that under severe wear

conditions the wear rank order of two tires establish under normal wear conditions can be reversed. Figure 4 gives an example. Two tires of different make, a test tire and a control tire, were wear-tested under severe and under normal conditions on the same test course (Reference 4). Normal wear was achieved by running the tires on a straight course; severe wear, by running them at various speeds on a 123-foot circle. We evaluated the given test data in terms of slip angle, and plotted them (on log paper, to cover the large range of wear rates) as function of wear rate, w, in mil/kmi. The resulting curves show that at low and medium wear severities, the test tire experiences less wear than the control tire; at higher wear severities, the ranking is reversed. Hence, if run on a highway under normal driving conditions, the test tire would rank higher than the control tire. Run under accelerated (severe) wear conditions, the control tire would outrank the test tire.

Under these circumstances it is not surprising that attempts to correlate normal and severe wear rates have failed. Figure 5 gives an illustration [5]. Wear tests were conducted on a route in Nevada with the objective to establish a correlation between tire wear rates experienced on automobiles (normal wear) and wear rates generated on towed trailers with the wheels set at a slip angle of 2.5 degrees (severe wear). The tires included bias-ply, bias-belted, and radial-ply constructions. Figure 5 demonstrates convincingly that for the tires tested no satisfactory correlation could be established between normal and severe wear rates; the ration w_{normal}/w_{severe} fluctuates between 1:20 and 1:80. We maintain, therefore, that to predict the wear resistance of tires, they must be tested under normal wear conditions.

Table 1. MAXIMUM VALUES OF SLIP ANGLE α AND LONGITUDINAL SLIP S RECORDED ON ROADS OF DIFFERENT DRIVING SEVERITY (AFTER REF. 3).

Road Severity	α deg	S %	Wear Rate mil/kmi
low	1.4	1.2	7
medium	1.8	2.1	16
high	3.3	2.9	70

low - 99% of accelerations <0.1 g
        (longitudinal and lateral)
medium - 99% of accelerations <0.2 g
        (longitudinal and lateral)
high - 99% of accelerations <0.4 g
        (longitudinal and lateral)
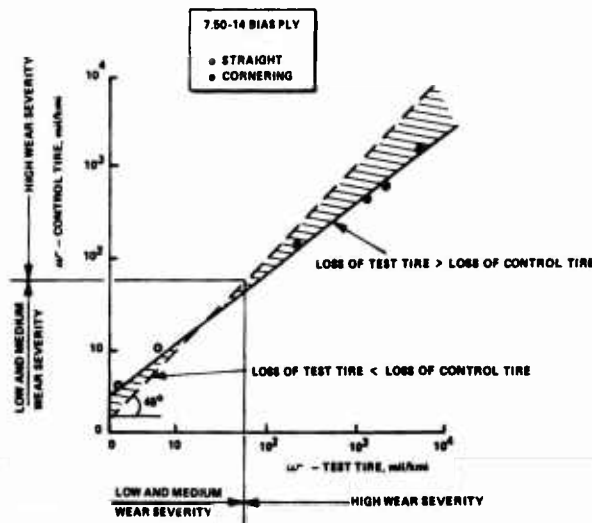
Figure 4. Influence of test severity on tire wear ranking (adapted from ref. 4).

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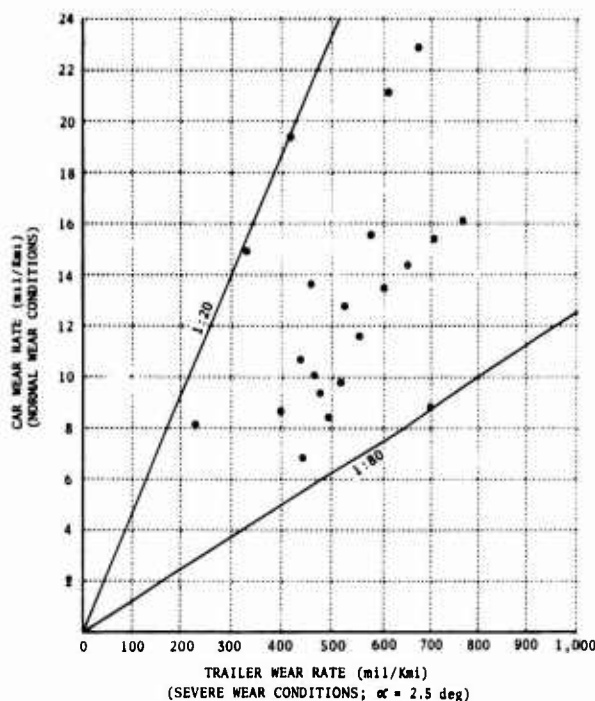
Figure 5. Correlation between normal-wear and accelerated-wear data for different tires (adapted from ref. 2).

Figure 6. Tire research machine.

TEST FACILITY

A photograph of the TIRF facility is shown as the frontispiece to this report; a dimensional view of the factility is shown in Figure 6. The primary features of the machine are:*

Tire Positioning System

The tire, wheel, force sensing balance and hydraulic motor to drive or brake the tire are mounted in the movable upper head. The head provides steer, camber, and vertical motions to the tire. These motions (as well as vertical loading) are servo controlled and programmable for maximizing test efficiency. The ranges of the position variables, the rates at which they may be adjusted, and other information are shown in Table 2.

Roadway

The 28-inch wide roadway is made up of a stainless steel belt covered with material that simulates the frictional properties of actual road surfaces. The belt is maintained flat to within 1 to 2 mils under the tire patch by the restraint provided by an air bearing pad which is beneath the belt in the tire patch region. The roadway is driven by one of the two 67-inch-diameter drums over which it runs. The road speed is servo controlled; it may be programmed to be constant or varied.

*A more complete description of this facility will be found in Ref. 6.

The test surfaces used on TIRF are made from a commercially available proprietary material called *Safety Walk.** The surface consists of a backing sheet treated with contact cement used to adhere it to the stainless steel belt. On the working side, a silicon carbide type of grit material is set in an epoxy type cement. This material is specified by its reflectance which we have found to be related to its microtexture and wet skid number. Standard practice is to use a surface with an initial wet skid number greater than the desired test value. The surface is then stoned with a grinding stone. The stoning serves to break off those sharp asperities which extend appreciably above the others. Stoned surfaces do not abrade the tire surfaces excessively, and they are stable under normal usage. Scanning electron microscope (SEM) photos have been taken of some of the surfaces used. Figure 7 shows SEM photos of one of the materials used in both the "as-received" and "after-stoning" condition.

Schonfeld of the Ontario Ministry of Transportation and Communications has developed a method of photo-interpretation of pavement skid resistance [7]. Samples of our material have been analyzed by Schonfeld who calculated skid numbers in general agreement with values which had been measured. The texture parameters used by Schonfeld are height, width, angularity, distribution and harshness of projections, and the harshness of the surface between projections. He classified the surface in terms of the apparent height and angularity of the microprojections: polished, smooth, fine-grained, coarse-grained subangular, and coarse-grained angular. A fine-grained surface has microprojections approximately 1/mm high while coarse-grained surfaces (angular or subangular) have projections approximately 1/2-mm high or

*Manufactured by 3M Company.

Table 2

TIRF CAPABILITIES

CHARACTERISTIC	RANGE
TIRE SLIP ANGLE (α)	$\pm30^{\circ}$
TIRE CAMBER ANGLE (γ)	$\pm30^{\circ}$
TIRE SLIP ANGLE, RATE ($\dot{\alpha}$)	10°/sec
TIRE CAMBER ANGLE RATE ($\dot{\gamma}$)	7°/sec
TIRE LOAD RATE (TYPICAL)	2000 lb/sec
TIRE VERTICAL POSITIONING	2"/sec
ROAD SPEED (V)	0-200 mph
TIRE OUTSIDE DIAMETER	18.5" to 46"
TIRE TREAD WIDTH	24" MAX.
BELT WIDTH	28"
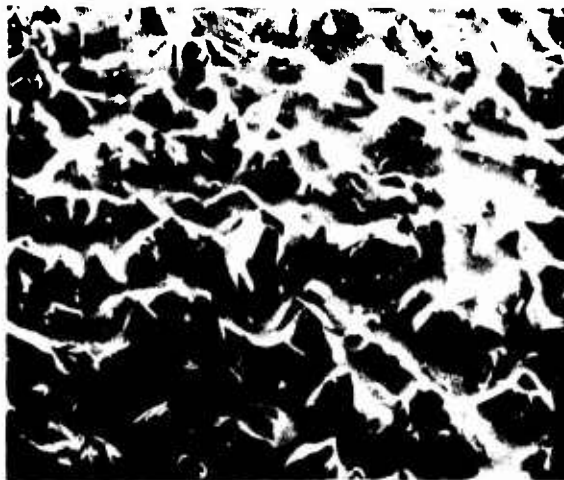
a. As-received

b. After stoning

Figure 7. Scanning electron microscope photos (15X) of safety walk surface.

higher. The Safety Walk surfaces fall between fine-grained and coarse-grained with about two-thirds of the projections being more than 1/4-mm high.

A unique feature of TIRF is the ability to carry out tests under wet road conditions. A two-dimensional water nozzle spans the roadway. This nozzle has an adjustable throat which can be set to the desired water depth. The flow through the nozzle is then varied by controlling the water pressure. At each test condition, the water film is laid on tangential to the belt at belt velocity. The film thickness may be varied from as low as 0.005 inch up to 0.5 inch.

Tire-Wheel Drive and Balance System

A drive system which is independent of the roadway drive is attached to the tire-wheel shaft. This separate drive allows full variation of tire slip both in the braking and driving modes. The tire slip ratio, referenced to road speed, is under servo control.

A six-component strain gage balance surrounds the wheel drive shaft. Three orthogonal forces and three corresponding moments are measured through this system. A fourth moment, torque, is sensed by a torque link in the wheel drive shaft. The load ranges of the basic passenger car and truck tire balances are shown in Table 3. Transfer of forces and moments from the balance axis-system to the conventional SAE location at the tire roadway inter-face is in the data reduction computer program.*

System Operation

Data Acquisition Program (DAP) Control

The data acquisition program (DAP) is a software system which controls machine operation and logs data during tests. DAP controls test operations by means of discrete setpoints which are generated in the computer by the program. These setpoints are sent to the machine servos which respond and establish tire test conditions. After the set-points are sent to the servos, a delay time is provided which starts after the machine variables

Table 3
BALANCE SYSTEM CAPABILITY

COMPONENT	PASSENGER CAR TIRE BALANCE	TRUCK TIRE BALANCE
TIRE LOAD	4000 lb	12,000 lb
TIRE TRACTIVE FORCE	±4000 lb	8000 lb
TIRE SIDE FORCE	±4000 lb	8000 lb
TIRE SELF ALIGNING TORQUE	±500 lb ft	1000 lb ft
TIRE OVERTURNING MOMENT	±1000 lb ft	3000 lb ft
TIRE ROLLING RESISTANCE MOMENT	±200 lb ft	400 lb ft

*More detailed information of the balance systems are their calibration may be found in Ref. 6 and 8.

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have reached a steady state value within predetermined tolerances. This allows the system to stabilize before data are taken. After data are taken, the next set of test conditions is established and testing continues.

One or two variables can be changed during DAP testing. The other test parameters are kept fixed throughout the test. Up to twenty data points can be used for each variable in a run.

A data reduction program is used to operate on the raw data collected during testing. These new data are reduced to forces and moments in the proper axis system and all variables are scaled to produce quantities with engineering units. Raw and reduced data are temporarily stored in a disc file. Both reduced and raw data can be transferred to magnetic tape and maintained as a permanent record.

Reduced data points can be listed, plotted and curves can be fitted to the points. All of the standard Calspan plots can be generated from DAP test data.

Data lists and plots are displayed on the oscilloscope screen of a CRT console. Hard copies of this information can be made off this display.

Continuous Sampling Program (CSP) Control

The continuous sampling program (CSP) is a software system which controls machine operation and continuously logs data during tests. Test variables can be constant or changed at rapid rates. One or all variables can be changed during a test. Data can be sampled at rates up to 100 samples per second. Pauses are used so that data can be logged during desired intervals of the test.

CSP testing can be conducted quickly which in turn reduces tire wear during severe tests. The high rate of data sampling also permits limited dynamic measurements to be made during testing.

Two parameter plots of data can be made. Carpet and family plots of test data cannot be made with this program at the present time. CSP data will also reflect time effects if tire characteristics are a function of the rate of change of testing variables.

Data reduction is accomplished in a manner similar to that employed in DAP testing.

Tread Wear Testing on TIRF Under Normal Wear Conditions

The advantage of tread wear testing under normal wear conditions (slip angle < 2 degrees, longitudinal slip < 2.5%) on an indoor testing machine such as TIRF instead of on the road is evident:

most factors contributing to wear can be tightly controlled. For instance, wear of a given tire can be be studied as a function of

Inflation Pressure

Vertical Load

Slip Angle (Cornering)

Inclination Angle

Road Velocity

Slip or Skid (Driving or Braking)

Tread Depth

It could be argued that wear testing on TIRF is qualitatively different from, and therefore inferior to, road testing in one important aspect: a vehicle on the road "seeks" its way by a "natural process of continuous adaptation to the everchanging external inputs, whereas on TIRF all tire factors are fixed during a test run. Hence, on the road, the tire is subjected to essentially transient conditions, whereas on TIRF it experiences only steady-state conditions. In the light of TIRF's capability to simulate transient conditions, however, this argument does not hold. The influence of many factors such as steering system suspension system, driver habits can be simulated by controlled time-dependent inputs. In fact, almost all parameters that a tire "sees" can be factored into a test cycle in a controlled fashion (except for a few weather inputs such as slush, snow, and ice). Table 2 indicates that slip angle as well as camber angle and vertical load can be varied rapidly, and so can road speed. TIRF's strength is its capability to quickly produce large sequences of tire service factors in a rigidly controlled fashion. Slip and inclination angles can be controlled within 0.03 degree; and tire and road speeds, within 0.08% (at 50 mph). Both tolerances are sufficiently small to ensure well-controlled wear tests under normal wear conditions (i.e., at small slip values). Similarly good accuracies are obtained for all other parameters controlled and recorded by TIRF such as inflation pressure, forces, moments, torque, and loaded radius.

Road tests are inherently incapable of yielding more than a few data points per tire; due to unavoidable "noise" in the form of weather changes, varying road conditions, driver inputs, vehicle feedbacks, etc., the acquisition of each datum point takes up a good part of the tire's total tread life. TIRF is largely free of this "noise." Therefore, the minimum test duration can be substantially reduced provided a short-duration test technique can be developed. The minimum duration of a wear test on TIRF is dictated by the accuracy of TIRF and the accuracy and test duration of the measuring technique, as discussed in the Experimental Errors section.

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PROGRAM OBJECTIVES

The major objecties of the program were to

Develop an electromechanical device that would measure losses in tread height with an accuracy of one mil or better.

Establish a short-duration wear test methodology under normal (not accelerated, or severe) wear conditions.

Determine relations between tire wear and load, slip angle, longitudinal slip (braking, driving), inflation pressure, and speed

Only one tire type was to be used -- a 7.00-16 LW military tire with NDCC tread pattern. Later, under a follow-on program, the test methodology worked out under this program was to be extended to include a larger variety of military tires.

WEAR MEASURING DEVICE AND WEAR PROCEDURE

To measure the change in tread height, we developed a simple mechanical-electrical device. Figure 8 indicates the measurement principle. The rigid frame of the instrument supported by the base area of the tread grooves establishes a fixed reference system unaffected by wear. The position of the wear surface with reference to the frame is measured at points A, B, C, and D by four linear variable differential transformers (LVDT's). Wear at the four points is determined by recording the LVDT positions before and after a wear run, as indicated in Figure 9. A picture of the device is shown in Figure 10.

The tread surface geometry is measured by placing the instrument successively at 12 stations around the tire (numbered 1-12) and three stations across the tread (numbered 13-15). With four surface measurements per instrument position, the total number of tread measurement points is 144. Figure 11 shows the distribution of measurement points

MEASUREMENT 1: BEFORE WEAR RUN
MEASUREMENT 2: AFTER WEAR RUN

Figure 9. Wear measuring technique (schematic).
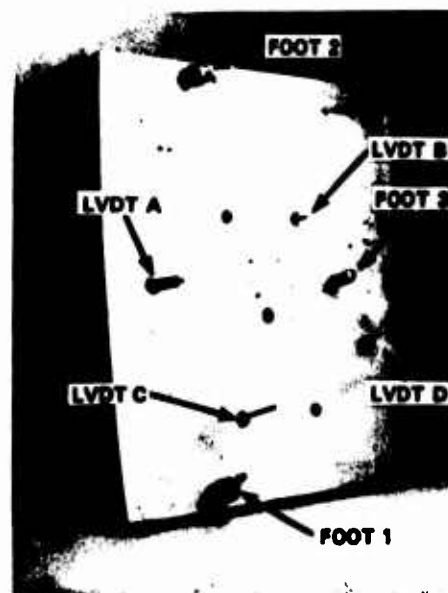
Figure 10. Wear measuring device.

Figure 8. Wear measuring device (schematic).
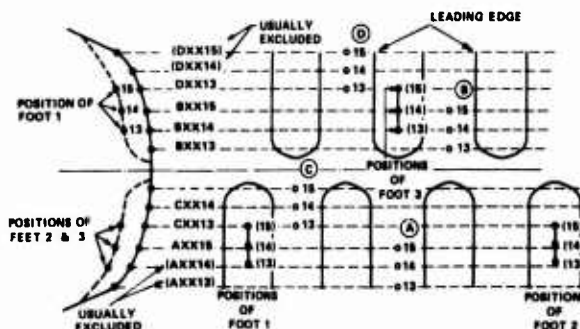
Figure 11. Distribution of wear measurement points at any one of the 12 stations around tire (XX from 01 to 12) total number of points = 12 x 12 = 144.

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for the three stations (13-15) across the tread. Each point is identified alphanumerically. For instance, A 09 14 designates the position of LVDT A at the angular station 09 and the lateral station 14. The outer positions AXX 13 and 14 and DXX 14 and 15 are usually not utilized because they fall outside the actual wear zone of the tread.

The 12 circumferential and three lateral stations were marked on the tread by crosshairs scratched lightly into a thin coat of white paint applied to the groove bases, as indicated in Figure 12 and also in Figures 25-29. No difficulties and only very small errors were encountered in placing the device repeatedly in the same position.

Before and after each tread measurement, the device was checked on a specially built calibration fixture, Figure 13. The stability of the four channels proved to be excellent. Figure 14 shows that long-term and short-term fluctuations were

small, of the order of 1/2 mil. In the analysis of single wear runs, the long-term fluctuations could be completely ignored; and the short-term fluctuations, reduced to negligible levels by proper averaging.

The device was integrated into the TIRF computer system so that wear data could be easily recorded and processed. Table 4 shows the computer output
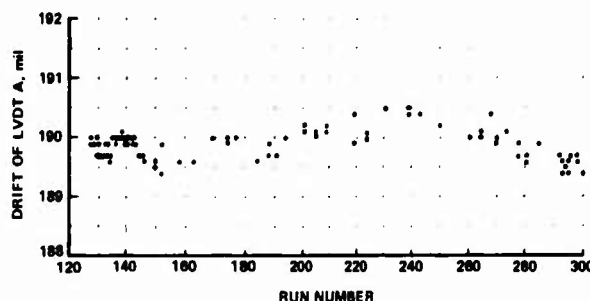
Figure 14. Drift of LVDT A.

Figure 12. Identification of angular and lateral stations.
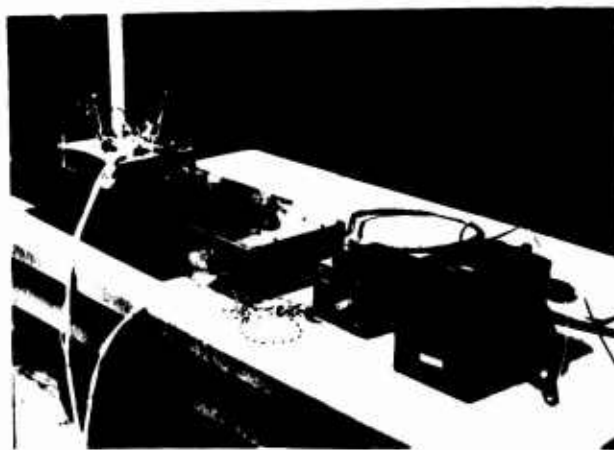
Figure 13. Calibration fixture for wear measuring device.

Table 4
EXAMPLE OF COMPUTER PRINT-OUT OF WEAR MEASUREMENTS
FOR A GIVEN LATERAL STATION (HERE, 14).

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of a typical wear run. For each of the 12 circumferential stations (of a given lateral station), and each of the four LVDT's A-D, the differences in tread heights measured before and after a wear run are printed out. Furthermore, the 12 differences of each LVDT are averaged and printed out together with the standard deviation (of single measurement). Hence, for each wear run, 12 averages (four LVDT's and three lateral positions) with 12 standard deviations are generated, indicating the wear of 12 meridians around the tire.

The procedure of measuring wear was as follows: the tire tread was first thoroughly cleaned and then marked for the wear measuring device. Following this, the tire was inflated and suspended for a few hours on a rack in an air-conditioned room. In this way, flat spotting and unequal temperature distribution were avoided. Then, the device, which had been calibrated shortly before, was placed on the designated 36 locations around and across the tire tread, and 144 measurements of the tread height were recorded, (Figure 15). This took about 10 to 15 minutes. Figure 16 shows a close-up of the device in position. The tire was then mounted on TIRF (Figure 17) and run under the specified conditions of speed, slip angle, load, time, etc. After the run, the tire was allowed to cool, and second tread height readings were taken at the same positions of the pre-wear readings. Finally, the data were printed out, as indicated in Table 4.

EXPERIMENTAL ERRORS

The tread heights measured before and after a wear run and their differences indicate not only the actual wear losses but a number of experimental errors as well. Our tests revealed six different sources of error; they are listed in Table 5.

Figure 16. Wear measuring device in position.

Figure 17. Test tire mounted on tirf.

Figure 15. Tread height measurements.

Table 5
SOURCES OF MEASUREMENT ERRORS

- RANDOM SOURCES

  - INSTRUMENTATION SYSTEM
  - WEAR FLUCTUATIONS (AROUND TIRE)
  - PLACEMENT OF WEAR MEASURING DEVICE ON DESIGNATED TREAD LOCATION (BEFORE AND AFTER A WEAR RUN)

- VISCO-ELASTIC-PLASTIC TREAD RUBBER PROPERTIES

  - SINKAGE OF WEAR MEASURING DEVICE INTO TREAD RUBBER
  - CREEP OF TREAD RUBBER AFTER TEST RUN
  - RESIDUAL RUBBER DEFORMATIONS

- TIRE BREAK-IN (PERMANENT CHANGE OF TIRE SHAPE)

- TIRE TEMPERATURE

  - THERMAL EXPANSION OF TREAD RUBBER (NEGLIGIBLE)
  - THERMAL DEFORMATION OF TIRE

- WEAR "DUST"

- WEAR HISTORY

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1. Random errors are caused by the instrumentation system, by wear fluctuations around the tire, and by slight misplacements of the wear measuring device during the measurement process. Table 6 shows that the mean values of the instrumentation and the placement errors are (nearly) zero; they are no biased. Hence, the accuracy of a wear measurement can be expressed in terms of the standard deviation. The standard deviation of the wear fluctuations around the tire is much larger than the standard deviations of both the instrumentation system and the placement process. Table 6 shows that with 96 measurement points around the tire (per wear test), the instrumentation system error is only 0.02 mil; and the placement error, 0.04 mil. The combined errors of all three sources amount to 0.16 mil, an error much smaller than the accuracy of 1 mil specified as desirable at the outset of this investigation.

2. Errors caused by the visco-elastic-plastic properties of the tread rubber are of a different kind than random errors; they introduce systematic offsets present in each measurement. Hence, they cannot be reduced by repetitions; their effects can be suppressed only by suitable modifications of the measurement technique.

We identified three sources of errors caused by visco-elastic-plastic rubber properties (Table 5): sinkage, creep, and residual deformation. Sinkage is characterized in Figure 18. As soon as the tread rubber is loaded by the wear meter, the device begins to sink into the rubber -- initially, at a rate of 0.3 mil/min; later, at a much slower rate of 0.1 mil/hour. Hence, if the measurement process can be kept within, say, 10 seconds, the sinkage error will be very small.

The visco-elastic behavior of a tire also accounts for the phenomenon of creep: after a run is completed and the load is removed, the tire returns slowly to its original shape. In Figure 19, a tire was loaded by 800 lb for one hour. Immediately after load release, continuous tread height measurements were taken. The initial compression of the tire tread was about 11 mils. The tread returned slowly toward its original height, first at a rate of 0.9 mil/min, later at 0.1 mil/hour. After 20 hours, the height was still off the original height by 2 mils.

The effects of creep on the measurement accuracy can be effectively reduced by introducing a waiting period of about one day after a wear run is completed. The effect of residual rubber deformation is unknown at this time and has to be explored further.

3. Tire break-in has a significant effect on wear measurements. It appears that during the first fifty miles or so of tire operation, certain internal bondages and stresses caused by the manufacturing process are relaxed, and the tire settles into a more permanent shape. Table 7

INITIAL RATE 0.3 mil/min
OVERALL RATE 0.1 mil/h
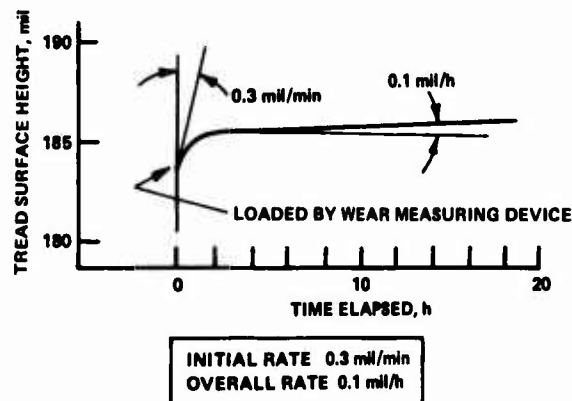
Figure 18. Instrument sinkage error.

Table 6
RANDOM (UNBIASED) ERRORS

● INSTRUMENTATION SYSTEM ERROR (CALIBRATION)

  ● MEAN 0.008 mil ≈ 0
  ● STANDARD DEVIATION 0.2 mil
  ● STANDARD DEVIATION OF MEAN (96 POINTS)   0.02 mil

● ERROR DUE TO WEAR FLUCTUATIONS AROUND TIRE

  ● STANDARD DEVIATION 1.5 mil
  ● STANDARD DEVIATION OF MEAN (96 POINTS)   0.15 mil

● ERROR DUE TO REPETITIVE PLACEMENT OF
  WEAR MEASURING DEVICE

  ● MEAN 0.06 mil (≈ 0)
  ● STANDARD DEVIATION 0.4 mil
  ● STANDARD DEVIATION OF MEAN (96 POINTS)   0.04 mil

              TOTAL (RANDOM) ERROR   0.16 mil

$$\left(= \sqrt{0.02^2 + 0.15^2 + 0.04^2} \right)$$
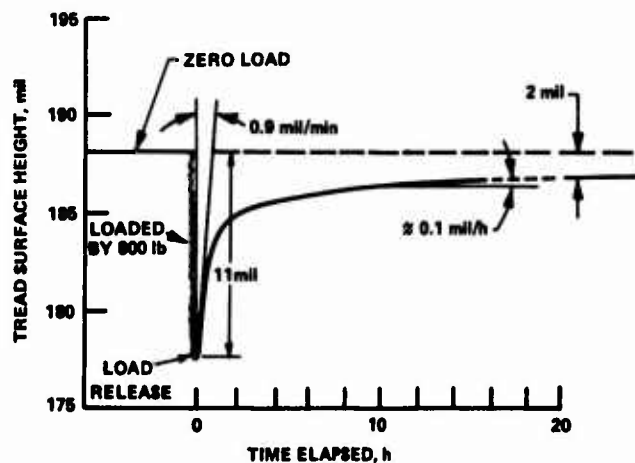
Figure 19. Creep error (after run).

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gives an illustration. The first wear runs of new tires showed a "wear" Δh (first) 2.3 to 5.8 times larger than the wear Δh (second) of the second run under identical run conditions. Therefore, the first fifty miles or so of a wear run cannot be utilized for wear measurements; they have to be considered part of the test preparation.

4. Temperature has a distinct effect on the measurement of wear. Figure 20 shows a sequence of tread surface measurements taken before and after a wear run. During the wear run, the tread temperature increased from 70 F to 135 F. A tread surface measurement immediately after the end of the run indicated a growth in tread height of 17 mils, which completely obscured the actual wear effects. As the tire cooled, the tread height decreased. When the pre-run temperature of 70 F was reached, the tread had contracted beyond the initial height by 2 mils -- the actual wear. Figure 21 shows that about four hours are needed after a run to stabilize the tread dimensions. Consequently, after each wear run, a cooling period of about six hours had to be introduced.

It later became obvious, however, that soaking alone was not sufficient to achieve consistent

results. Figure 22 shows wear rates measured repeatedly on the same tire under identical wear conditions. Although soak periods of at least 24 hours were observed, we found rather large fluctuations among the wear rates measured after the first break-in run. Further investigations revealed that these irregularities were caused by rather small temperature changes that occurred in the soak periods between pre-run and post-run measurements. In Figure 22, the higher rates are associated with a drop in temperature; the lower rates, with an increase. The temperature changes were small, of the order of a few degrees F. We knew, of course, that rubber would thermally expand and shrink, but we estimated these effects to be very small. It was, therefore, surprising to learn that one or two degrees F would change the shape of the tread rather drastically. A possible explanation is that under the influence
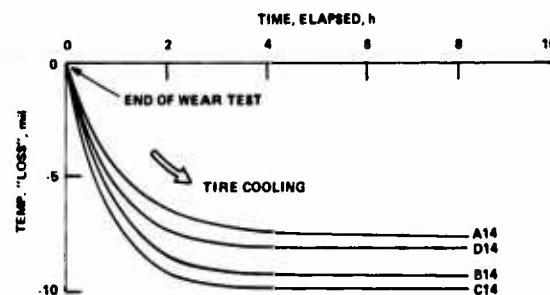
Figure 21. Effect of tire cooling on tread surface measurements (wear measuring deveic stationary).

Table 7
BREAK-IN ERROR

RUN CONDITIONS	BREAK-IN DISTANCE MILES	Δh (FIRST RUN) / Δh (SECOND RUN)
$\alpha = 0°$	180	5.8
$\alpha = \pm 0.5°$	30	4.8
$\alpha = \pm 1.0°$	60	4.2
$T = +100$ ft lb	60	5.7
$T = -100$ ft lb	60	2.3

Δh IS THE DIFFERENCE OF TREAD SURFACE MEASUREMENTS TAKEN BEFORE AND AFTER A WEAR RUN

Figure 20. Temperature effects on tread surface measurements.
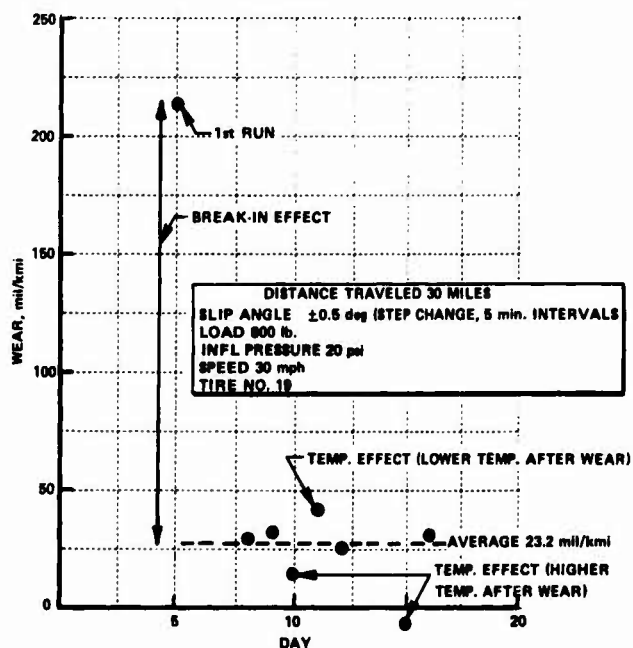
Figure 22. Repeatability of wear results.

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of temperature the tire cords contract or expand and in this way deform the tread significantly, as indicated in Figure 23. We then systematically heated and cooled a tire by a few degrees and measured the changes in tread height. Figure 24 shows that the average change of tread height with temperature was about 0.5 mil/deg F. As a consequence of this rather large temperature effect, it appears necessary to control the temperature of the soak area within narrow limits, depending on the accuracy required.

5. During a wear run, small rubber particles accumulated on the tread surface; they had to be brushed off to avoid measurement errors.

6. Different wear conditions generate different wear patterns. Tested under free-rolling conditions, for instance, a tire develops parallel wear bands at both sides of the center ridge (Figure 25). Under cornering conditions, with the slip angle varying sinusoidally, the wear is more evenly distributed across the tread surface (Figure 26). However, parallel ridges may develop in certain areas. These ridges have been described

SLIP ANGLE	0°
LOAD	800 lb
INFL PRESSURE	20 psi
SPEED	30 mph
DISTANCE TRAVELED	90 miles

Figure 25. Wear pattern of free rolling tire.
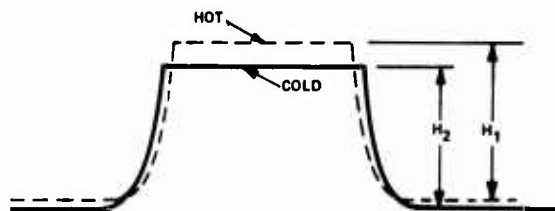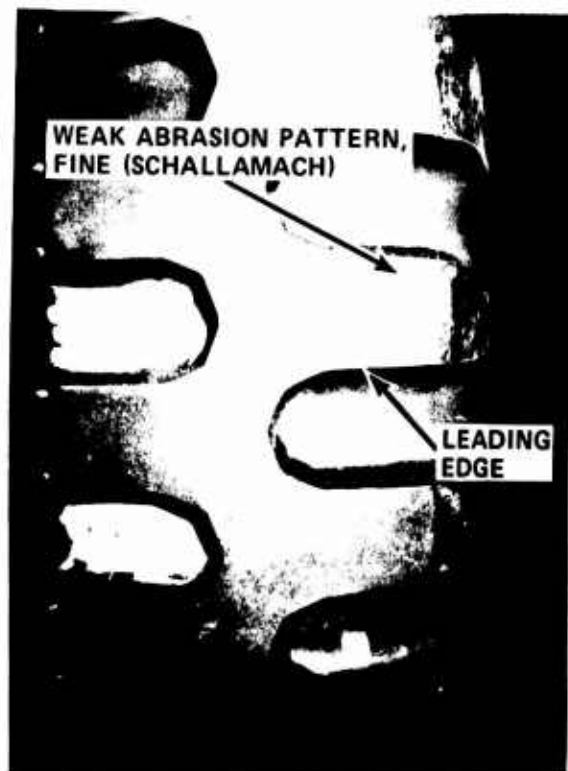
Figure 23. Thermal tire deformation (conjectured).

Figure 24. Change of tread surface measurements at points A13-D15 with tire temperature, at a constant inflation pressure (20 psi) Δh≈0.5 mil/°F.

SLIP ANGLE	±1° (sinusoidal; 0.1 Hz)
LOAD	800 lb
INFL PRESSURE	20 psi
SPEED	60 mph
DISTANCE TRAVELED	240 miles
TIRE NO.	28

Figure 26. Wear pattern of cornering tire.

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by Schallamach [9] in detail and are, therefore, often called Schallamach waves. Their intensity depends on many factors such as coarseness of the road surface, stiffness of the rubber, and direction of relative motion between tread and road. Very coarse Schallamach waves were observed when the tire was subjected to driving (Figure 27). Under braking, step wear developed between the center ridge and the tread logs (Figure 28); also, the trailing edges of the logs showed considerably more wear than the leading edges. Under combined braking and cornering, additional Schallamach waves could be observed on the center ridge (Figure 29). In Appendix B, some footprints of worn tires are presented on which the various wear patterns can again be identified.

From this, it is obvious that the topography of the wear surface depends strongly on the wear conditions imposed. It also follows that the amount of rubber abraded under given wear conditions depends on the wear history. For instance, the wear obtained from a cornering test that was preceded by, say, a free-rolling test is different from the wear of the same cornering test obtained from a new tire never wear-tested before. Therefore, to secure consistent results, each wear test should be started from a new tire.

Table 8 lists again the six major sources of errors and the means to eliminate or reduce them, as discussed.

TEST PROGRAM

The test program encompassed four common types of tire operation

Straight free-rolling

Cornering under free-rolling

Straight driving and braking

Cornering under driving and braking

In addition, the influence of load, speed, and tire pressure on wear were investigated. All
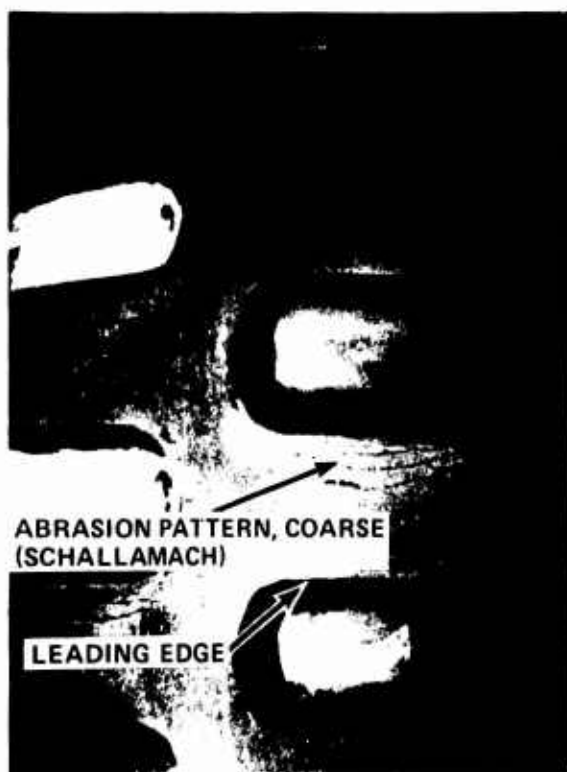
TORQUE	+100 ft/lb
SLIP ANGLE	0°
LOAD	800 lb
INFL PRESSURE	20 psi
SPEED	60 mph
DISTANCE TRAVELED	240 miles
TIRE NO.	30

Figure 27. Wear pattern of driving tire.
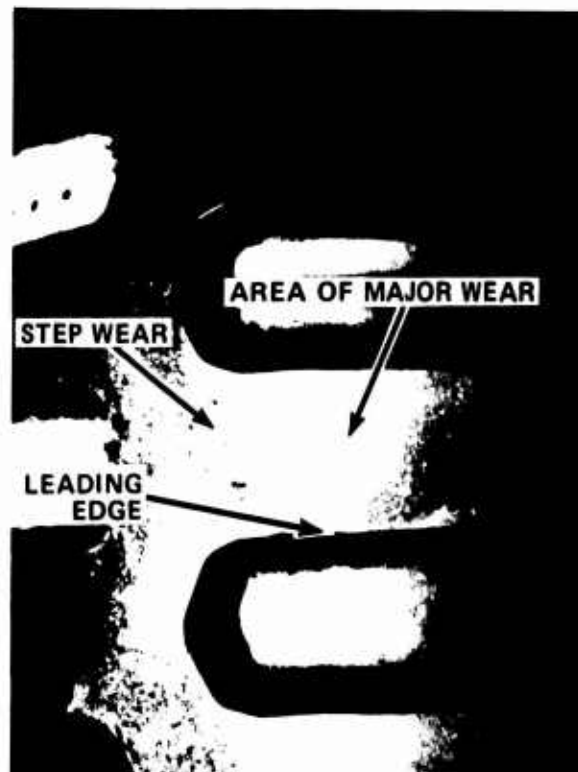
TORQUE	-100 ft/lb
SLIP ANGLE	0°
LOAD	800 lb
INFL PRESSURE	20 psi
SPEED	60 mph
DISTANCE TRAVELED	240 miles
TIRE NO.	29

Figure 28. Wear pattern of braking tire.

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ABRASION PATTERN, FINE (SCHALLAMACH)

AREA OF MAJOR WEAR

LEADING EDGE

STEP WEAR
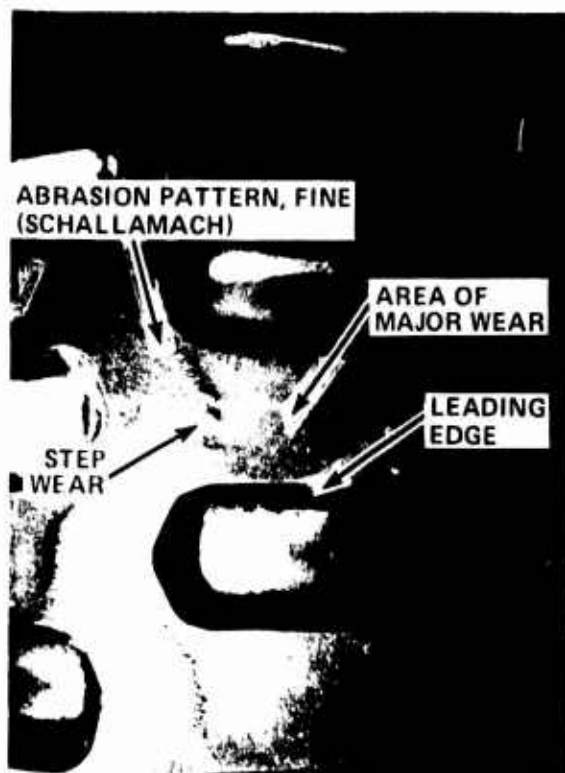
TORQUE	-100 ft/lb
SLIP ANGLE	±1° (sinusoidal; 0.1 Hz)
LOAD	800 lb
INFL PRESSURE	20 psi
SPEED	60 mph
DISTANCE TRAVELED	240 miles
TIRE NO.	32

Figure 29. Wear pattern of braking/cornering tire.

Table 8
ELIMINATION OR REDUCTION OF MEASUREMENT ERRORS

- **RANDOM SOURCES**
  - **LARGE NUMBER OF WEAR MEASUREMENT POINTS AROUND TIRE**
- **VISCO-ELASTIC-PLASTIC TREAD RUBBER PROPERTIES**
  - **LIGHT-WEIGHT PROBE**
  - **RAPID MEASUREMENTS**
  - **24 h WAITING PERIOD AFTER TEST BEFORE TAKING MEASUREMENTS**
- **TIRE BREAK-IN**
  - **30 MIN BREAK-IN UNDER TEST CONDITIONS**
- **TIRE TEMPERATURE**
  - **SAME TIRE TEMPERATURE FOR MEASUREMENTS BEFORE AND AFTER WEAR RUN**
- **WEAR DUST**
  - **BRUSHING**
- **WEAR HISTORY**
  - **NEW TIRE FOR EACH NEW TEST CONDITION**

tests were performed on 7.00-16 LW NDCC military tires. Under normal military service conditions, this tire experiences loads between 765 and 1035 lb at pressures between 20 psi and 25 psi. The operating speed does not surpass 50 mph.

To keep the test conditions in reasonable agreement with actual service conditions, it was decided to vary the

load between 800 lb and 1200 lb

inflation pressure between 16 psi and 24 psi

slip angle between ±2 degrees

torque between +100 ft-lb (driving) and -100 ft-lb (braking)

The torque of ±100 ft-lb is associated with low longitudinal slip values of about ±0.6 percent. Hence, the ranges of both α and s covered in this program are basically in agreement with the ranges called out in Table 1 for normal driving severity.

To simulate actual driving conditions to some degree, and to avoid asymmetrical wear, the slip angle was varied periodically during testing, either sinusoidally or stepwise. In both cases the frequency was low, between 1/10 (sinusoidal change) and 1/600 Hz (step change). The table in Appendix A gives an overview of all tests run. Note that the first runs were all experimental runs to check out the equipment and to develop a viable test technique.

The test procedure was developed in context with the results of the error analysis, described in the Experimental Errors section. Accordingly, for each test, a new tire was used. The tread surface was thoroughly cleaned and carefully marked for the wear measuring device. The tire was then inflated and run on TIRF for 30 minutes under test conditions. After this break-in run, the tire was soaked for at least 12 hours in an air-conditioned room before the tread height was measured at the designated locations and recorded on magnetic tape. Following this, the actual wear run was performed. After the run, the tire was soaked again for at least 12 hours in the air-conditioned room, and measurements were taken and recorded. Finally, the differences in tread height and their standard deviation were computed and printed out.

TEST RESULTS AND COMPARISON WITH FIELD TESTS

The test results describe the influence of load, inflation pressure, slip angle, and braking and driving on wear.

Two Mansfield tires were run at 800-lb and 1200-lb load under otherwise identical test conditions. The wear results are plotted in Figure 30. They suggest that for the tires tested, wear increases proportionally with load.

In Figure 31, wear is plotted for three Mansfield tires with different inflation pressures. The load was kept at 800 lb (the design load for 20 psi). Wear appears to increase rapidly at inflation pressures lower or higher than the design pressure at design load.

Figure 32 depicts wear data measured as a function of slip angle for a number of Mansfield and Firestone tires. During wear runs, the slip angle was alternated stepwise between ±α max in five-minute intervals, to avoid asymmetrical wear. Wear is strongly dependent on slip angle; the TIRF data in Figure 32 plotted on semi-log paper indicate an exponential relation of the type

$$w = a\,e^{b\alpha}$$

For comparison, the road data (cornering) of Reference 4 (plotted in Figure 4) are superposed; they follow the same relation -- a confirmation of our contention that TIRF or a similar laboratory machine can indeed be used to simulate road wear performance. Figure 32 indicates that the Mansfield tires are wearing slightly less than the Firestone tires, by about 17 percent.

$$w_F/w_M = 1.2$$

In Figure 33, the results of braking and driving tests are plotted. The tests were performed with

Figure 30. Wear versus tire load.
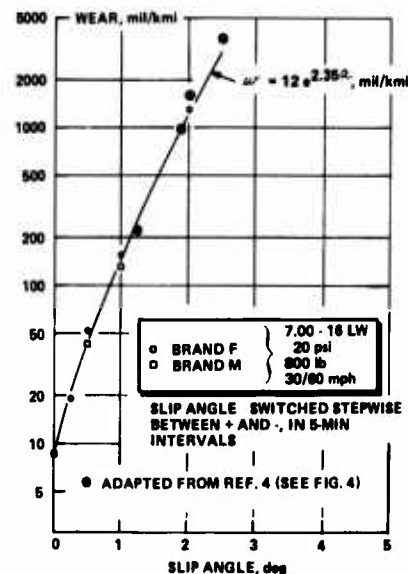
Figure 32. Wear versus slip angle.

Figure 31. Wear versus inflation pressure.
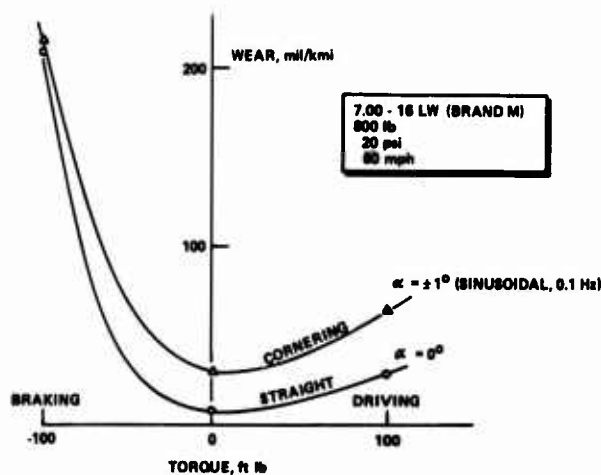
Figure 33. Wear versus torque.

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and without simultaneously cornering the tire. In both cases, braking losses are much higher than driving losses -- a consequence of the fact that the displacements of tread elements in the contact area of a braked tire are much larger than those of a driven tire. According to Veith [2], the frictionally dissipated energy in the contact patch of a braked tire is 2.4 times larger than the energy dissipated in the patch of a driven tire, for the same absolute torque of 180 ft-lb. Here, the ratio is even larger -- 3.4 for the cornering tire, and 7 for the straight-rolling tire, perhaps a consequence of the coarse cross-country tread pattern. The cornering-driving tire experiences higher wear than the straight-driving tire, as expected. The wear values of the cornering-braking and the straight-braking tires, however, are nearly equal, for reasons unknown at this time.

Direct comparisons of the wear results generated in this program with road results are frustrated by the fact that road tests are usually performed under random variations of slip angle, load, speed, etc. Indirect comparisons, however, are possible in two ways.

1. The tread surface exposed to different wear conditions assumes different microscopic wear patterns. Figures 34 through 39 are scanning electron microscope (SEM) tread surface photos of Mansfield tires tested on TIRF under various wear conditions. Most of the depicted tread surfaces exhibit particular Schallamach wave patterns, depending on the wear condition imposed. For comparison with TIRF-generated surfaces, a SEM tread surface photo was made of a Mansfield tire that had been in practical use as a rear tire on a jeep (Figure 40). Its wear pattern shows close resemblance to the pattern of the tire tested on TIRF under driving and cornering conditions (Figure 39). We take the similarity between the two patterns as an indirect proof of TIRF's capability to simulate actual road wear conditions.

2. Another indirect comparison between TIRF and road wear data is offered by test data published in Reference 10. In these tests, NDCC military tires, size 7.00-16, were mounted on 1/4-ton trucks, 4 x 4 M 151 A2 (jeep), and tested at various speeds on paved roads, secondary roads, and open terrain. For Mansfield* tires, the following wear data were measured per 600 miles on paved roads (Table 8, Truck No. 3; Reference 10):

Free-rolling Left Front (770 lb) w = 12 mils; std. dev. 7 mils

Free-rolling Right Front (770 lb) w = 10 mils; std. dev. 7 mils

*In the report, Mansfield tires were coded by letter W. (Personal communication, Mr. Richard Heinrich, TACOM)
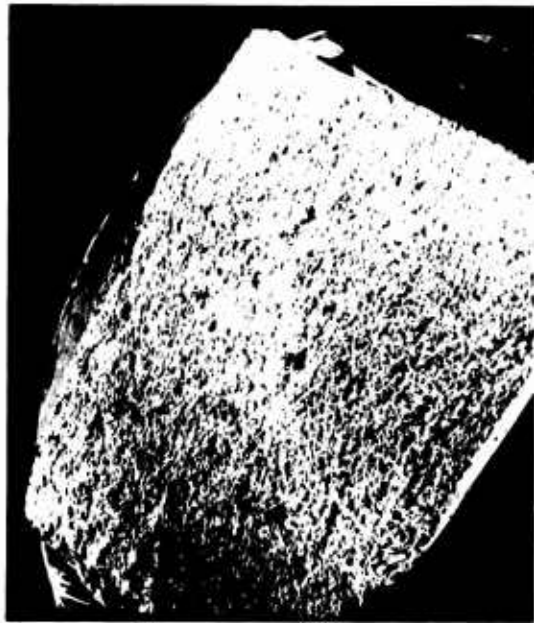
Figure 34. Scanning electron microscope photo (12X) of tread surface.

Test Condition: Tirf
$\alpha = \pm0.5^o$ (square wave, 1/600 Hz)
Tire Brand M

Figure 35. Scanning electron microscope photo (12X) of tread surface.

Test Condition: Tirf
$\alpha = \pm1^o$ (sinusoidal, 0.1 Hz)
Tire Brand M

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Figure 36. Scanning electron microscope photo
(12X) of tread surface.

Test Condition: Tirf
Straight Braking (-100 ft/lb)
Tire Brand M
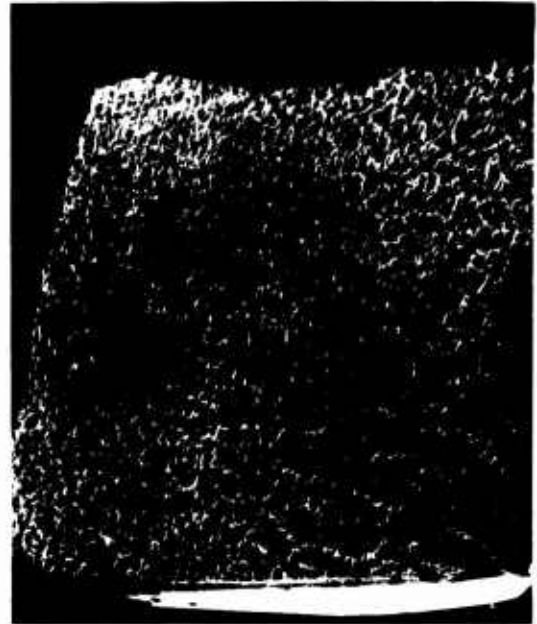
Figure 38. Scanning electron microscope photo
(12X) of tread surface.

Test Condition: Tirf
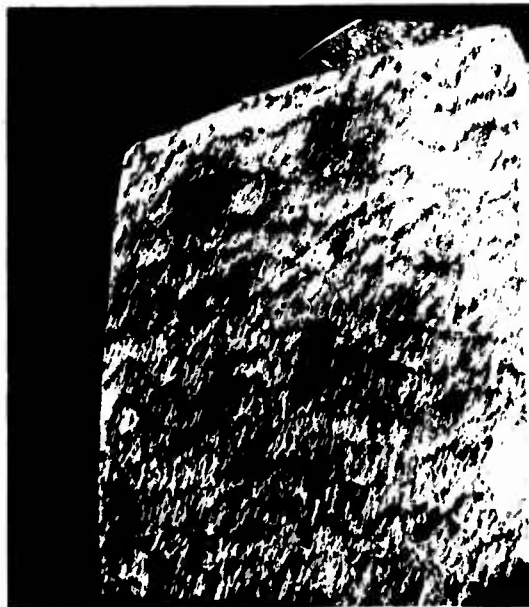Straight Driving (+100 ft/lb)
Tire Brand M

Figure 37. Scanning electron microscope photo
(12X) of tread surface.

Test Condition: Tirf
Braking - Cornering (-100 ft/lb)
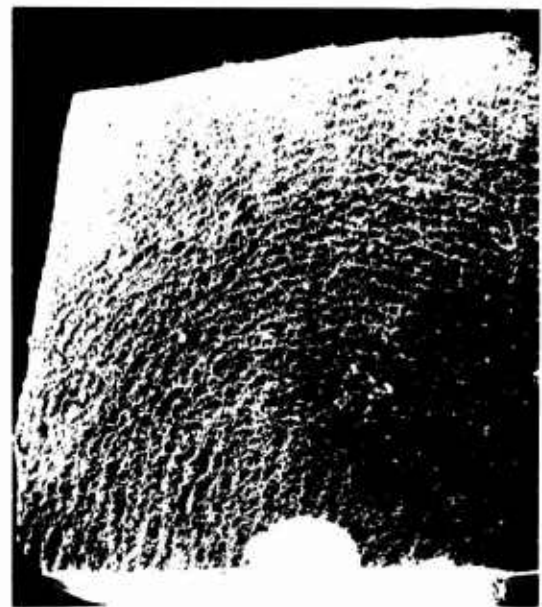$\alpha = \pm 1^o$ (sinusoidal, 0.1 Hz)
Tire Brand M

Figure 39. Scanning electron microscope photo
(12X) of tread surface.

Test Condition: Tirf
Driving - Cornering (+100 ft/lb)
$\alpha = \pm 1^o$ (sinusoidal, 0.1 Hz)
Tire Brand M

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Figure 40. Scanning electron microscope photo
(12X) of tread surface.

Test Condition: Jeep
                Field Conditions
                Tire Brand M (Rear)

Driven   Left Rear (1043 lb)
             w = 58 mils; std. dev. 19 mils

Driven   Right Rear (1043 lb)
             w = 63 mils; std. dev. 12 mils

For the free-rolling tires, then, the average wear rate was 18 mils/kmi (std. dev. 12 mils); for the driven tires, it was 101 mils/kmi (std. dev. 26 mils).

To compare these road wear rates with rates measured on TIRF, we first computed the slip angle that produces a wear rate of 18 mils/kmi under front wheel load. Using TIRF data, we found this slip angle to be ±0.6 degree (sinusoidal variation, 0.1 Hz) -- a plausible result (see Table 1). With this angle, we produced an estimate of the rear tire wear under rear wheel load.

Using average numbers for aerodynamic resistance and tire rolling losses, we computed a rear wheel torque of 100 ft-lb. Under pure driving with no braking (slip angle ±0.6 degree), this torque corresponded to a wear rate of 70 mils/kmi. With 17% braking, the wear rate rose to 100 mils/kmi -- the value measured on Yuma Proving Ground.

Of course, the slip angle of ±0.6 degree, the slip angle frequency of 0.1 Hz, the torque of ±100 ft-lb, and the percentages of driving and braking of 83% and 17%, respectively, are all

educated guesses of the actual driving conditions of the jeep tested. In view of the many uncertainties, however, the agreement between TIRF and Yuma data must be considered satisfactory.

CONCLUSIONS AND RECOMMENDATIONS

Wear resistance, one of the most important properties of pneumatic tires, has been measured in the past almost exclusively in road tests, either under normal (passenger car) or accelerated conditions (trailers). Both methods have serious drawbacks. A third method that would combine the advantages of the controlled, short-term trailer tests with the real-life wear conditions of passenger car tests was, therefore, highly desirable.

With TIRF, an opportunity was given to develop such a method. TIRF features a flat surface, a large speed range, realistic road surfaces, and the capability to simulate a large variety of wear cycles under tight control of slip angle, load, speed, etc. This program is primarily concerned with the development of an efficient test methodology that would permit the determination of a tire's wear loss after only a few hours' run of normal severity. This objective has been achieved with excellent results.

An electromechanical wear measuring system has been developed with an accuracy of 0.2 mil (st. dev. of single measurement).

A short-duration, wear measuring procedure for normal-driving (low-severity) conditions has been developed including

    A tire break-in of 30 minutes under test conditions

    Wear runs at controlled slip angle, load, speed, torque, etc., on TIRF with wear durations between 30 minutes and 3 hours

    Wear measurements at more than one hundred tread locations at constant tire temperature

    Computer storing and processing of wear data

The major sources of experimental errors (due to temperature, tire creep, and nonuniform wear) have been identified and either eliminated or reduced to low noise levels.

A wear program has been performed on 7.00-16 LW military tires under various conditions of inflation pressure, load, speed, slip angle, and driving and braking torque.

The test results indicate that in the range of normal driving (up to 2 degrees slip angle, 1200-lb load, and ±100 ft-lb torque), wear (in mil/kmi) is

An exponential function of slip angle

A linear function of tire load

reaches a minimum at design pressure or 20 psi

is many times higher for braking than for driving

Direct comparisons between TIRF measured and vehicle measured wear data are frustrated by the fact that the wear conditions of vehicle tests are usually varying randomly within rather large ranges. Under these circumstances, indirect comparisons were tried -- with good success. (1) It was noted that the microwear pattern of the tread surface, i.e., the Schallamach waves, observed (under a scanning electron microscope on the tread surface of a tire worn in actual road use was similar to that indicated on an identical tire tested on TIRF under corresponding, simulated road conditions. (2) Road wear data measured by the U. S. Army on the Yuma Proving Ground could be reproduced from TIRF data with the help of estimated wear cycles that presumably had prevailed during road testing. Both results permit the conclusion that short-duration wear data generated on TIRF adequately reflect actual wear conditions on the road. Hence, it can be expected that on TIRF or a similar indoor machine, valid wear data can be generated in a few hours' wear time under normal wear conditions.

With these favorable conclusions, a reliable basis is provided for an expansion of this program. The following steps are suggested:

A wear cycle reflecting average road wear conditions should be devised. The cycle could be either of deterministic or of random nature, or it could contain a combination of deterministic and random elements. For instance, the slip angle could be varied randomly according to a normal distribution, whereas the associated loads could be made dependent on the slip angle.

Noise and uncertainty levels in wear measurements should be reduced further.

The electromechanical wear measuring instrument should be redesigned to accommodate different tread patterns.

A number of tires of different size, construction type, and tread design should be tested and ranked with respect to their wear resistance.

Results from these tests should be correlated to those obtained by TACOM on the same tires.

The results should also be used to specify a simple tire wear machine based on Calspan's flat-bed Simulated Roadway Unit (SRU) concept. SRU's are currently manufactured under a Calspan license and can be readily adapted to wear applications.

QUESTIONS AND ANSWERS

Q: (Mr. Shaver) Are the facilities at your testing facility available to industry and if so, on what basis?
A: Indeed they are available. Just contact us and we will give you a price. The machine is available, and we will do the study for you. This is our business. This machine, by the way, was funded by the major tire manufacturers and by the Government 2-1/2 to 3 years ago and since then we have been doing studies for industry and for the government -- various studies mostly force and moment measurements and wear studies for which this machine is ideal.

Comment: (Vogel) We should add, the machine is available on-site in Buffalo. It weighs a couple of hundred tons so it wouldn't be available in the field.

Q: How do you monitor your temperature? Do you use any infrared radiometers?
A: We have two infrared instruments, and we also have feedback control. One infrared instrument measures the road temperature, another one looks at the tire surface and tread surfaces and we have an inside probe that measures cavity temperature.
Q: What is the maximum load capacity of the equipment?
A: There are two balances, one for passenger car tires and one for truck tires. With passenger tires we can go up to 12,000 lb altogether, but for passenger we normally go only to 2,000 or 3,000. If we have to go higher, we use a truck balance which we can go up to 12,000, usually it's 8,000 or so.
Q: Is there a written paper available covering what you have talked about?
A: Yes, that is, I have to write a report on this and it will be available in a month or two.

APPENDIX A. TEST SCHEDULE

TACOM TIRE TEST SCHEDULE

RUN NO. (20-1)	TIRE NO.	TIRE BRAND	TYPE OF RUN	DATE (1975)
1	6	FIRESTONE	WEAR CHECK POSITION 14	10/14/75
2			WEAR RUN	
3			WEAR CHECK	
4			WEAR RUN	
5			WEAR CHECK	
6			WEAR RUN	
7			WEAR CHECK	
8				10/15/75
9				
10				
11				
12				
13				10/16/75
14				
15				
16				
17				
18			1 MIN WEAR RUN	
19			WEAR CHECK	
20			WEAR CHECK	
21			10 MIN WEAR RUN	
22			WEAR CHECK	
23			10 MIN WEAR RUN	
24			WEAR CHECK	
25			WEAR CHECK	
26			WEAR CHECK	
27	8	FIRESTONE	10 MIN WEAR RUN POSITION 14	10/16/75
28			WEAR CHECK	
29			WEAR CHECK	
30			MIN WEAR RUN	
31			WEAR CHECK	
32			WEAR CHECK	
33			10 MIN WEAR RUN	
34			WEAR CHECK	
35			WEAR CHECK	
36			WEAR CHECK	10/17/75
37			WEAR CHECK	
...				
41			1 HR WEAR RUN	
42			WEAR CHECK POSITION 14	
53	6	FIRESTONE	WEAR CHECK POSITION 14	10/24/75
54			INSTRUMENTATION CHECK	

TACOM TIRE TEST SCHEDULE

RUN NO. (20-1)	TIRE NO.	TIRE BRAND	TYPE OF RUN	DATE (1975)
105	12	FIRESTONE	WEAR CHECK POSITION 14	11/13/75
106	14			
107	11			
108	9			
109	10			
110	5			11/14/75
111	13			
112			INSTRUMENTATION CHECK	12/4/75
113			LVDT CHECK	
...				
119	19	MANSFIELD		
...				

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TACOM TIRE TEST SCHEDULE

RUN NO.	TIRE NO	TIRE BRAND	TYPE OF RUN	DATE

TACOM TIRE TEST SCHEDULE

RUN NO.	TIRE NO	TIRE BRAND	TYPE OF RUN	DATE

Leading Edge

EAST ↓

Tire No.	28 (new)
Load	800 lb
Speed	-- mph
Pressure	24 psi
Slip angle	0 deg
Torque	0 ft lb
Run duration	0 min

Leading Edge
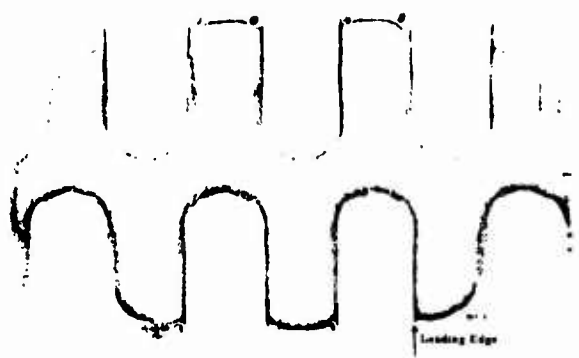
EAST ↓

Tire No.	24
Load	800 lb
Speed	60 mph
Pressure	20 psi
Slip angle	±1 deg (square)
Torque	0 ft lb
Run duration	30 min

Leading Edge
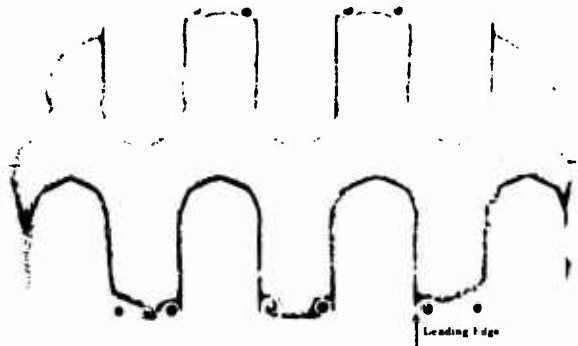
EAST ↓

Tire No.	19
Load	800 lb
Speed	30 mph
Pressure	20 psi
Slip angle	±, 5 deg (squar.
Torque	0 ft lb
Run duration	180 min

Leading Edge
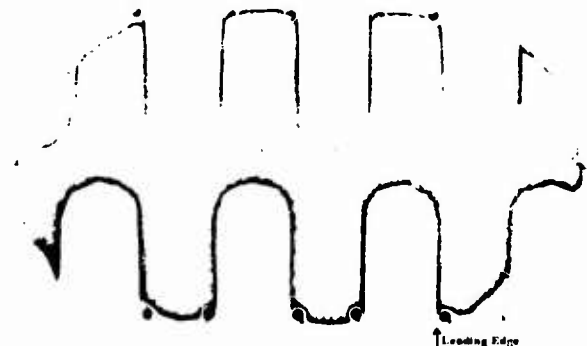
EAST ↓

Tire No.	25
Load	800 lb
Speed	60 mph
Pressure	20 psi
Slip angle	±1 deg (sinus.)
Torque	0 ft lb
Run duration	180 min
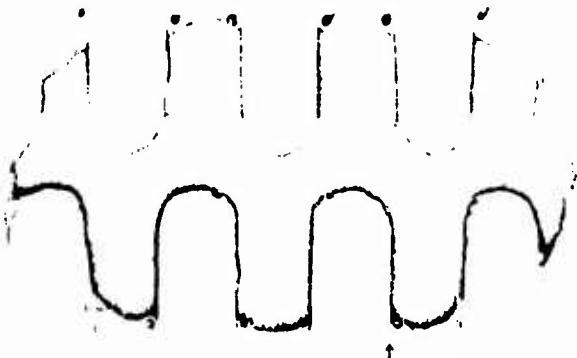
Leading Edge

EAST ↓

Tire No.	23
Load	800 lb
Speed	60 mph
Pressure	20 psi
Slip angle	0 deg
Torque	0 ft lb
Run duration	180 min
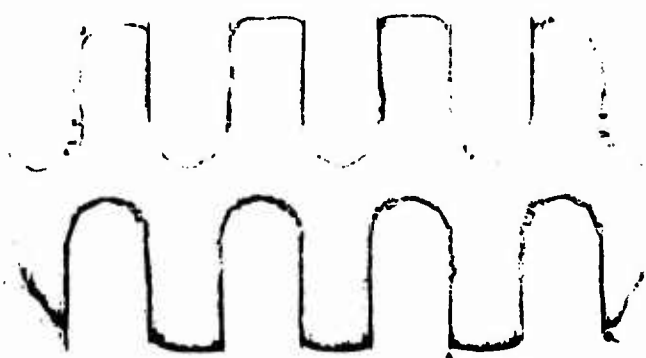
Leading Edge

EAST ↓

Tire No.	26
Load	1200 lb
Speed	60 mph
Pressure	20 psi
Slip angle	±1 deg (sinus.)
Torque	0 ft lb
Run duration	180 min
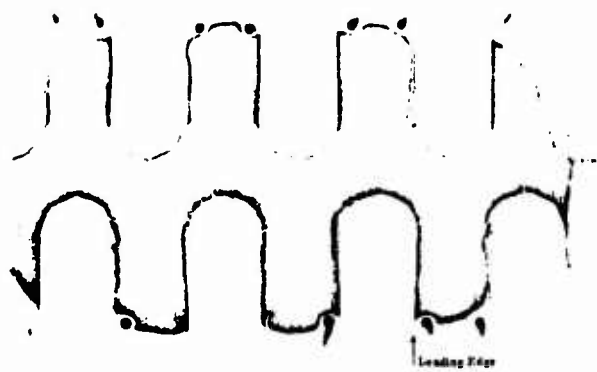
Leading Edge

Tire No.	27
Load	800 lb
Speed	60 mph
Pressure	16 psi
Slip angle	±1 deg (sinus.)
Torque	0 ft lb
Run duration	180 min
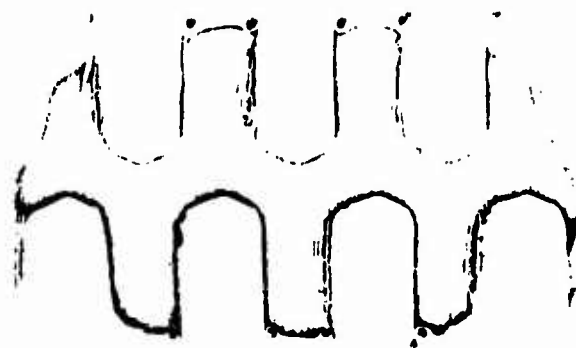
EAST ↓

Tire No.	30
Load	800 lb
Speed	60 mph
Pressure	20 psi
Slip angle	0 deg
Torque	+100 ft lb (driving)
Run duration	180 min
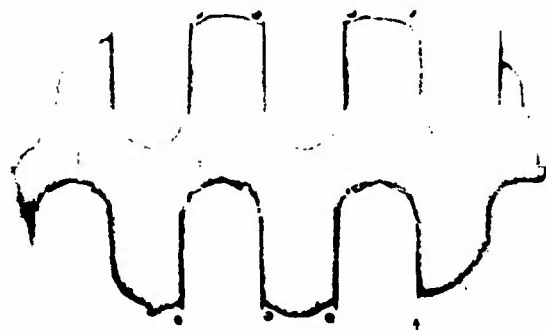
EAST ↓

Leading Edge

Tire No.	28
Load	800 lb
Speed	60 mph
Pressure	24 psi
Slip angle	±1 deg (sinus.)
Torque	0 ft lb
Run duration	180 min
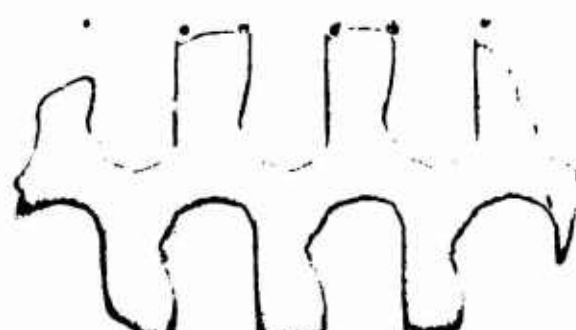
EAST

Leading Edge

Tire No.	32
Load	800 lb
Speed	60 mph
Pressure	20 psi
Slip angle	±1 deg (sinus.)
Torque	-100 ft lb (braking)
Run duration	180 min
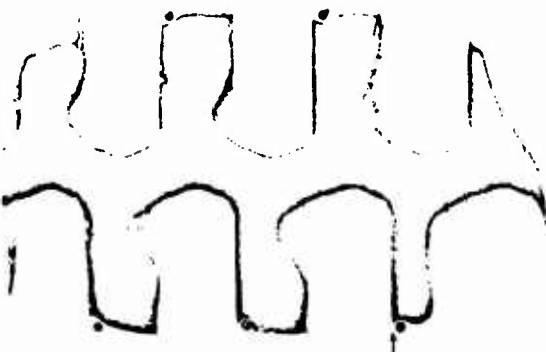
EAST ↓

Leading Edge

Tire No.	29
Load	800 lb
Speed	60 mph
Pressure	20 psi
Slip angle	0 deg
Torque	-100 ft lb (braking)
Run duration	180 min
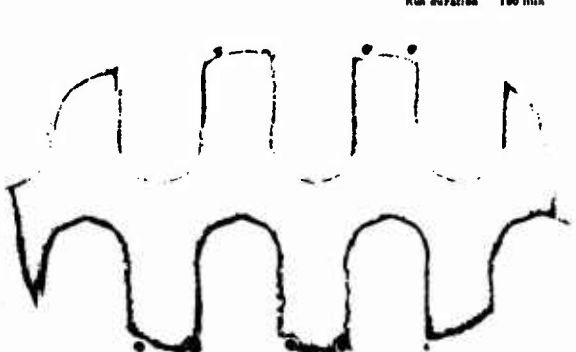
EAST ↓

Leading Edge

Tire No.	33
Load	800 lb
Speed	60 mph
Pressure	20 psi
Slip angle	±1 deg (sinus.)
Torque	+100 ft lb (driving)
Run duration	180 min

EAST ↓

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A SEMI-AUTOMATED PULSE-ECHO ULTRASONICS SYSTEM FOR INSPECTING TIRES

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The Transportation Systems Center in Cambridge, Mass. has developed and is presently evaluating a semi-automated pulse-echo ultrasonic tire testing machine. This paper describes the machine and explains its functioning in relation to the special requirements for ultrasonic inspection of tires.

A general overview of the tire-handling part of the machine is shown in Figure 1. As can be seen, it is an immersion system with a big tank about four-feet deep. This technique utilizes the effectiveness of total immersion to avoid any possibility of difficulties due to reflection of the ultrasound by air bubbles, which would be carried into the water as the tire rotates for scanning if it were only partially immersed.

As shown in Figure 2, the tire is mounted on a split rim and inflated with the aid of a pneumatic cylinder device which removes and installs the outer rim half. The rim halves are held together against the outward thrust of the inflation pressure by a heavy bayonet latch inside the tire. The cylinder thrusts toward the tire, grips the outer rim-half with a group of electromagnets (the outer rim-half is made of steel, nickel plated), and holds it while the tire-scan motor rotates the stub shaft 45° to unlock the bayonet latch. The air cylinder is then retracted to permit removal and replacement of the tire, and

the process is reversed. The tire is inflated and deflated through the shaft assembly.

There are three such split-rim tire stations, on the ends of the three arms of a large spider or vertical carousel. Whenever one arm is at the load/unload position, the other two stations are totally submerged, one at a debubbling position, and the other at an inspection position. Once a tire has been mounted, it is moved to the debubbling station by a 120° rotation of the spider, driven by a 1-horsepower cam-actuated Ferguson index drive, shown in Figure 3. At the same time the previously debubbled tire is carried to the inspection station, and the previously inspected tire is brought to the unload/load station.

The Ferguson drive could index the spider in about two seconds if suitable baffles, curtains, etc., were added to control the splash. If tire mounting were totally mechanized, loading and unloading could also be accomplished in a few seconds. As we shall see, the actual ultrasonic scanning could readily be accomplished within about two seconds. If the data were evaluated automatically, a throughput of four to six tires per minute could readily be obtained. At the present stage of development, however, the index time is slowed down to about five seconds to avoid excessive splash. The tire mounting cycle is slowed to about 20 seconds for operator safety.
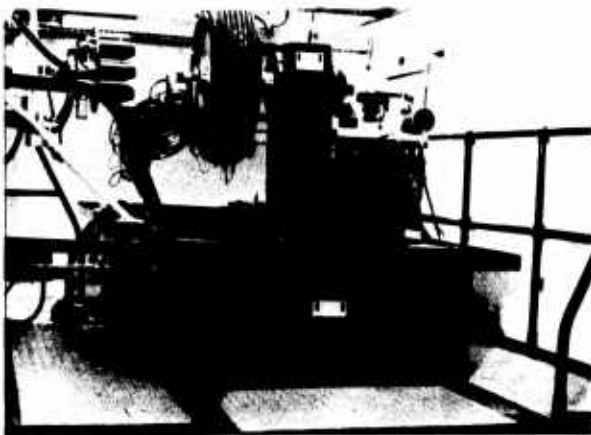
Figure 1. Overview of tire handler. A 3-station vertical carousel carries tires from the unload/load station shown, to a debubble station and an inspection station. The tire is totally submerged for debubbling and inspection to avoid entrainment of surface air bubbles.

Figure 2. Tire Loading: Outer rim half is gripped by electromagnets and removed by a pneumatic cylinder. Outwaved thrust of inflation pressure is supported by an internal bayonet latch, which is rotated for engagement and disengagement by the tire-scan stepping motor.

While one tire is being scanned, the next tire is being debubbled by a set of high velocity water jets, but the load/unload operation cannot be conducted simultaneously, because reverse rotation is required to unlock the bayonet latch, and the three stub shafts are coupled mechanically by a roller chain drive inside the spider and driven by a single stepping motor. Finally, the scanning time itself is stretched out to 10 seconds because of the limited power of the scanning motor. For the present system, the mechanical limit on throughput is a little better than a tire per minute.

As shown in Figure 4, a set of transducers is arranged in a ring around the cross section of the tire. The transducers (up to 24 in number) are pulsed in sequence, and the returning echo signals are processed in sequence with the aid of electronic switching. Thus, the entire surface of the tire is scanned during a single revolution, which requires ten seconds. The transducers are sequenced at a rate of 2.4 kHz, so each of them is pulsed 1,000 times during the rotation, and 24,000 spots on the surface of the tire are interrogated during the ten seconds of the scan.

The system operates in the pulse-echo mode: each transducer sends out a short pulse of ultrasound lasting about two thirds of a microsecond, which travels through the water and into the body of the tire. Echo signals are reflected back to the same transducer from the various structural elements, e.g., belts, plies, etc., and finally from the inner surface of the tire. The only ultrasonic limitation on scanning rate is the requirement that all of the echoes from a given pulse be received before the next pulse is sent out, and for suitable transducer spacing from the

tire, this time would be about 70 microseconds. In this case the same data would be acquired in approximately 1.7 seconds.

To make the pulse-echo technique work for tires, the second special requirement, no less important than total immersion, is to have the transducers perpendicular to the layered interfaces inside the body of the tire, so that specular reflections from the reinforcing elements can be received. To facilitate such mechanical alignment, the transducer support yoke is pivoted on sleeve bearings, at the main axis of the spider, so that it can be swung up near the surface of the water as shown in Figure 5. The spider is stopped halfway in an index operation and then jogged and hand cranked to bring the tire up to the surface, such that it will be in the same position relative to the transducers as in the inspection position. Thus, the coarse mechanical adjustments involving manual adjustment of clamping screws, slides, etc., can be reached while the transducers are totally under water, and it is possible to observe the echo signals on an oscilloscope. The criterion for proper alignment is simple: the echo signals are maximized and the layered structure is resolved to the maximum possible extent. Mechanical positioning of the transducers relative to the outer surface of the tire is not a practical approach to this problem because the outer surface of the tire is seldom parallel to the internal layered structure of the reinforcing materials.

To make the transducer adjustment procedure as easy as possible, each transducer is mounted on a small manipulator mechanism, so designed that the various required adjustments are as nearly independent as possible. Figure 6 shows one of these manipulators and illustrates the kinematics of the design. Transducer manipulators are mounted alternately on the top and bottom sides
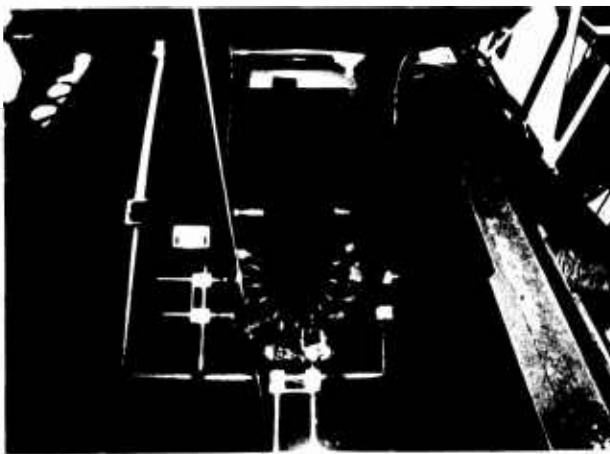
Figure 3. Indexing of spider - 120° rotation advances tires from load/unload station to debubble and inspection stations.

Figure 4. Transducers in working position.

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of three arc segment rails having an H-shaped cross section, one of which is shown. These rails are called "ϕ-rails" because the position of each transducer along its supporting ϕ-rail corresponds to what we call the ϕ-coordinate, which measures angular position around the center of the cross section of the tire. The ϕ-angle is taken to be 0° towards the wheel axle, and increases from about 90° at the center of the blackwall (serial number) side of the tire, through 180° at tread center, to 270° at the whitewall side, etc. The three ϕ-rail segments can be positioned independently to make their arc centers coincide approximately with the local center of curvature for the adjacent ply layers in the tread region, and in each side of the tire, respectively. The normal to the tire structure then coincides approximately with a radius of the ϕ-rail, and would do so exactly if the tire shape were exactly circular over the corresponding ϕ-segment. To accommodate small departures from this ideal, a correction angle denoted by α can be introduced by moving the transducer on a smaller arc slide referred to hereafter as the "α-slide." Each α-slide can be positioned in or out along a radius of the ϕ-rail so that the arc center of each α-slide lies within the tire body at the depth of the ply layer of most interest. Motion along the α-slide is thus equivalent to rotation about the volume element of the tire being inspected, and changes in the angle of incidence in the beam can be made without changing the volume element being examined. Finally, the transducer can be moved in and out along a radius of the α-slide to achieve the desired water path distance, and each transducer can be tilted up or down from the cross section plane to make the beam axis perpendicular to the tangent plane in that direction too. This design may appear at first to be overly complex;

however, a simpler design would be much more tedious to set up, because the various adjustments would be highly interacting. For successive tires of the same design the only adjustment which is very critical and likely to change much, is the α-angle. Remote adjustment of the α-angle is provided by a small stepping motor on each manipulator. This remote trimming capability permits precise reflection amplitude measurements to be made without the results being confused by minor changes in tire shape. Coarse adjustments that have to be made manually are only required when there is an appreciable change in tire size or shape.

Figure 7 shows an overview of the scan control and data evaluation console. To the right can be seen a rack containing 24 pulser-receiver amplifiers, one for each of the transducers. The main rack encircled by the operator's table contains the control electronics and the signal processing and display elements of the system. Lighted pushbuttons select and indicate scanning, signal processing, and display modes. Scan data displays are generated on a scan converter image memory tube and presented for evaluation on a large TV monitor. Signal processing is digitally controlled, and the scan-programmed signal processor provides up to 32 adjustable parameters which can have independent values for each of the 24 channels. A laboratory oscilloscope providing an "A-scope" presentation can be selectively triggered to monitor the effects of adjustments of the parameters for any one channel at a time. The knob panel directly in front of the operator, shown close up in Figure 8, is effectively switched to control 18 of the available parameters for the selected channel viewed on the A-scope. Digital values corresponding to the knob settings can then be loaded into the control memory. By

Figure 5. Transducers in position for coarse mechanical alignment.

Figure 6. Transducer manipulator kinematics.

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repeating this process for each of the channels,
appropriate parameters can be loaded to suit a
given size and type of tire.

To assist the operator in the managing and re-
cording of these parameters, a minicomputer pro-
vides a tabular display of the parameter values
as shown in Figure 9 and permits entry or alter-
ation of selected parameters via the keyboard,
and/or re-entry of parameter sets from a digital
storage medium.

Either the scan-data image-format displays from
the large TV monitor, or the alphanumeric param-
eter displays shown on the small TV monitor, can
be printed on paper by a video facsimile recorder
(out of view in the figures). Finally, behind
the operator's shoulders in Figure 7, you could
see the reels of a video tape recorder. When a
tire is scanned, the raw, unprocessed echo signals
can be recorded. Thereafter, any of the various
kinds of signal processing and display functions
that the system is capable of can be accomplished
from the tape-recorded signal, even after the
tire is no longer available for tests.

Prior to describing the various signal processing
and display functions of the system in more de-
tail it is first appropriate to note some of the
characteristics of pulse echo returns from tires
which have motivated the design of this system.

Figure 10 shows echo signals correlated with the
internal structure in the tread region of a
belted tire where there were four body plies and
two belt plies. The upper echo signal was
obtained with a transducer having a nominal
resonant frequency of 1.0 MHz, while the lower
trace was obtained with a 5.0 MHz transducer.
The upper trace shows a sharp, three half-cycle,
return from the outer surface of the tire, which
is characteristic of the echo signals seen from
simple plane interfaces with highly damped trans-
ducers. Here we see the third special requirement
to make pulse-echo inspection of tires work:
highly damped transducers must be used so that
the emitted pulse is short enough to give useful
resolution of the layered structure. The return
from the outer surface of the tire for the 5.0
MHz transducer appears more complex, merely be-
cause it is a summation of echoes from various
surface elements of the tire at slightly different
distances from the transducer. Reflections are
seen from the deepest grooves in the tread pattern
(e.g., at 5.0 cm on the 1 MHz trace and at 4.2 cm
on the 5.0 MHz trace) because the ultrasonic beam
cross section (about 1 inch in diameter) is
occupied partly by ribs and partly by grooves.
Shortly thereafter, a larger oscillatory signal
is returned from the ply layers, and finally a
pulse resembling the initial pulse in shape but
inverted, and much broadened, is returned from
the interface between rubber and air at the inner

Figure 7. Scan control and data evaluation console.
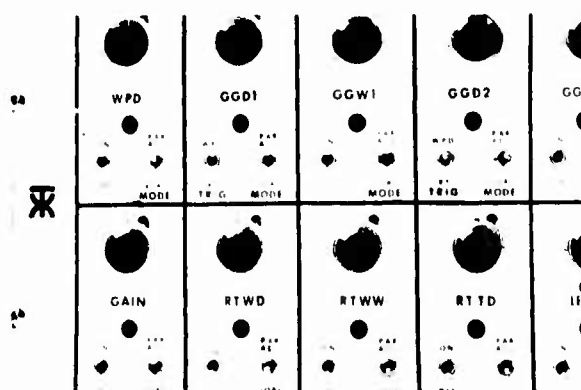
Figure 8. Parameter adjustment knobs. If mode switch is at
parameter adjust, system uses knob-generated value for selected
transducer instead of value from parameter memory. Load
position puts knob value in memory.

Figure 9. Tabular display of signal processor parameters.
Numeric input will replace or increment parameter value for
a particular transducer #, selected by positioning the cursor
as shown, or for all transducers if cursor is positioned before
beginning of a row.

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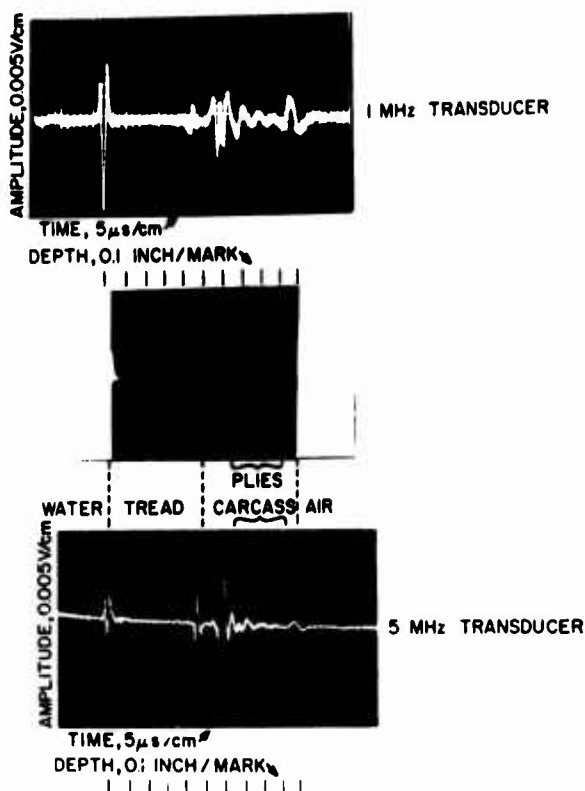
Figure 10. Reflection signal matched to tread structure of belted tire section.

surface of the tire. The amplitude of the return from the plies decreases very rapidly with depth, more rapidly for the higher frequency transducer, and returns from greater depths in the tire structure exhibit a low-frequency character. Since the incident pulse is short in time, it has a very broad frequency spectrum, and the returns from deep within the tire structure constitute primarily the low-frequency components of the signal which are less strongly absorbed and scattered. Because of these effects, it is not practical to use frequencies high enough to permit pulses short enough to cleanly resolve the successive layers in the ply structure. At this frequency the oscillatory return from the ply structure still exhibits interference effects between the returns from the several layers.

We have fitted our machine with 2.25 MHz transducers as a tentative choice for the trade-off of resolution versus penetration. Nevertheless, there is sufficient depth resolution to indicate the depth of a defect or anomaly relative to the various structural elements. There is certainly sufficient resolution to tell the difference between a bubble or air film on the surface of the tire and a separation or other defect with the body of the tire. The pulse-echo technique is thus inherently foolproof with respect to false

alarm indications due to inadequate wetting or entrained air bubbles which may have caused difficulties with previous immersion ultrasonic systems which used through-transmission techniques.

Figure 10 simultaneously proves the promise and exhibits the fourth fundamental difficulty of inspection of tires with ultrasonics. Clearly ultrasound penetrates the tire structure, as is evidenced from the substantial return from the inner surface of the tire, even at 5 MHz, and echo signals are certainly returned from the layered structure of reinforcing materials. However, the echo signal is complex. Furthermore, it is not only unique to the particular tire construction (number of plies, materials used, etc.) the thickness of tread, etc., but the echo signal is different at every spot around the cross section of a given tire. The situation is entirely different from that usually prevailing in metals testing, where the body of the material is homogeneous, and the presumption is that any echo from an internal volume element represents a defect. In such a situation, a very simple form of automated processing is highly effective: a time window or range gate is established which excludes echoes from the front and back surfaces of the tested object, and echoes within this gate exceeding some established threshold correspond to defects. In tires the situation is not so simple. The internal volume of the tire body returns echo signals from the normally present cord structure. To be sure, echo signals from such gross defects as a separations exceed the background of reflections from normal tire structure and therefore, are detectable with gate-and-threshold techniques. However, at the time this machine was conceived, there was increasing evidence that separations were neither a necessary nor a sufficient cause for tire failure. Thus it appeared that more subtle anomalies needed to be investigated - anomalies which would not necessarily give echo signals rising above the background of normally present reflections from ply structures, but which might be evidenced by perturbations of the amplitude, or perhaps the phase, of the normally present signals.

The B-scan display technique provides a very sensitive means for detecting any such perturbations of the normally present echo patterns. Figure 11 illustrates the technique with scan data taken on a programmed-defect tire having separations approximately 1/2", 1", and 2" in diameter, deliberately introduced between the belt and the body plies. The reflection amplitude signal is used to intensity modulate the beam of an oscilloscope, which is then displaced vertically in synchronism with mechanical scanning produced by rotating the tire relative to the fixed transducer. The image display shown was produced in four sections by recording the face

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Figure 11. Single-channel B-scan display.

surface trace, and the nonuniformity of the under-tread rubber is shown by the variable spacing of this line from the belt reflection. Large bright spots indicate strong echoes from the separations, clearly at a depth corresponding to the interface between belt and body plies.

The fact that the lines generated by reflections from the tire surface and ply structure are ir-regular, that is, that they are wavy rather than straight, indicates a lack of perfection in the roundness of the tire, since the position of a trace, of course, is a measure of the travel time (and hence distance) from the transducer to the reflecting structural element and back. Dimensional nonuniformity measurements can probably be related to force variation measurements. Furthermore, some kinds of shape anomalies appear to be worth checking as possibly safety related.

Pulse-echo ultrasonics provide a unique capability to make precise measurements of the dimensions and shape of the structural membrane of cord materials in an inflated tire. The position of a particular structural element can be measured directly from the ultrasonic echo time, rather than inferred by measuring mechanically to the outer surface and allowing for an assumed constant thickness of rubber outside this element. Since the velocity of sound in tire rubber is only about 10% higher than for water, the effect of variations in thickness of the outer rubber will be reduced by 90% as compared to a direct mechanical measurement.

We have seen that the B-scan display provides a powerful technique for revealing even very subtle variations in the echo returns from the tire structure. However, photographic recording would be prohibitively expensive for high volume use, and the time delay involved in processing would be incompatible with real-time evaluation. Both the materials expense and the processing delay are avoided by recording the display on an image memory scan converter tube. This device operates in some ways like a TV camera tube. It contains a semiconductor storage electrode on which an image can be written in the form of a varying density charge pattern by scanning it with an intensity modulated electron beam. The resulting charge image can then be read out by scanning the storage surface with the same electron beam, to give a video signal which will display the image on a TV monitor. Our system provides a number of signal processing and display formats, but the fundamental one is the multichannel B-scan display illustrated in Figure 12. Each of the vertical strips is a B-scan display for rotation of the tire from 0° to 360° for one of the transducers disposed around the cross section of the tire. As in the previous slide, the depth, or thickness dimension, of the tire structure is measured left-to-right within each B-scan strip.

of the oscilloscope on Polaroid film during successive 90° intervals of rotation. The ultrasound is reflected from the tire, starting of course with the outer surface, and the further inside the tire structure the reflecting interface, the later the time at which the echoes return. Thus, the horizontal axis (corresponding to the time axis of the oscilloscope) measures depth into the tire structure. The bright line at the left of the display is the reflection from the outer surface of the tire, while the bright ridges on the right are the reflections from the belt and ply layers. The less intense line just to the left of the belt reflection comes from the deepest grooves in the tread pattern. Thus the depth of the tread is measured by the horizontal distance to this trace from the outer

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The functioning of the signal processing and display electronics to produce this and other displays will be explained with reference to the functional block diagram shown in Figure 13. As the master clock produces timing pulses, the T-counter generates sequential transducer addresses to control the pulser-receiver multiplexer. A different transducer is pulsed every 400 microseconds, and the sequential echo signals are passed to the input of the signal processing electronics and also to the video tape recorder. The block diagram is shown with the first selection switch in the SCAN position, in which case a display is generated from the signals coming
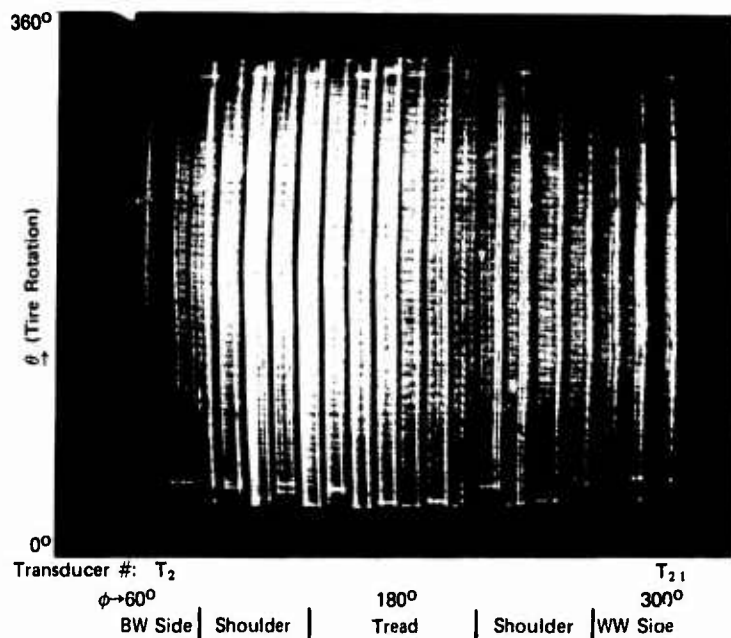
Figure 12. Multi-channel B-scan display.
(-B signal, B-planar display mode)
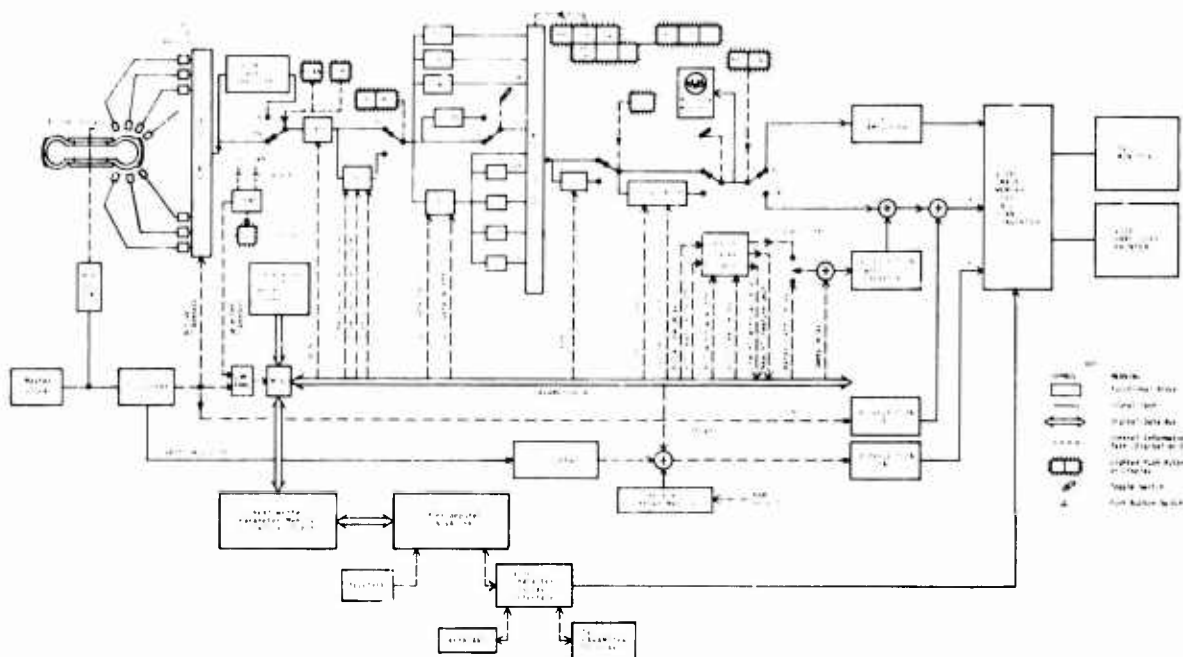
Figure 13. Functional block diagram indicating signal
processing and display modes.

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directly from the tire. In the PB or playback position, previously recorded sequential echo signals would be processed just as though they were coming live from a tire scan. The dotted lines indicate control of this switching by the lighted pushbuttons labelled SCAN and PB, which can be seen in the upper right hand corner of the mode control panel shown in Figure 14. Assuming the "B" option is selected by the next pair of interlocked buttons, the input to the signal processors will be affected by the scan-programmed gain values for each transducer, but not by the time-varied gain stage. If the B output of the signal processor multiplexer is selected by the next group of mutually exclusive pushbuttons, and the PBL display mode option is selected, (i.e., all switches in the positions shown on the diagram), the echo signal is passed directly through to the Z-input to intensity-modulate the electron beam of the scan-converter tube. The write beam is deflected to an appropriate x-position corresponding to the transducer number and a y-position corresponding to the rotational position of the tire by digital/analog conversion of the transducer count value and the θ-count value. At an appropriate time corresponding to the arrival of the echo return from the tire (normally the sum of Water Path Delay and Sweep Delay), the write beam is unblanked for about 32 microseconds, while the x-deflection sweep generator moves the beam across the width of one of the 24 display segments.

Figure 15 shows the A-scope presentation which guides the operator in adjusting parameters and selecting processing options for the previously shown display as well as certain others. The top trace shows the output of the pulser-receiver multiplexer with the oscilloscope triggered at the time of the "main bang" or excitation pulse for transducer number 7. At 20 microseconds per centimeter, only the echo signal from this transducer is seen. The operator will normally activate the Water Path Delay knob and adjust until the unblanking pulse covers the tire echo signal
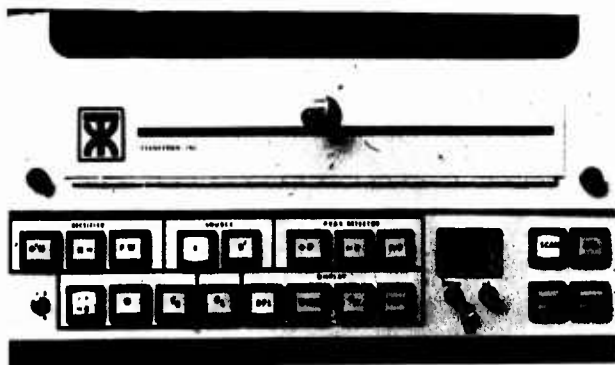
or as in this case, selects that part of it of most interest. The delayed sweep of the A-scope is triggered by the rising edge of the unblanking pulse, and the main sweep is intensified for the duration of the delayed sweep, which is made to coincide with the length of the unblanking pulse. The selected portion of the echo signal is shown with the expanded delayed sweep on trace 3. In this case the -B signal has been chosen to provide a maximum signal for separations, which have a negative reflection coefficient, since they represent a transition from the high acoustic impedance of tire material to the low acoustic impedance of air. A prominent separation reflection occurs at about 3.5 cm on this trace. This is the signal which was used to generate the multichannel B-scan display shown previously in Figure 12, and the separation, in the shoulder of the tire, accounts for the bright white spot at approximately $\theta=180°$ on the sixth B-scan strip of that figure (the 0th and 1st transducers were not mounted and the B-scan segments are not written).

Tires can easily be tested on a go-no go basis for defects such as this which give large signals compared to the background signals in their immediate neighborhood. The G-pushbutton is pressed, whereupon the button is lighted to indicate that the G-signal is the selected output of the signal processor multiplexer. The G-Gate Delay and G-Gate Width knobs are activated, and the gate is positioned to include the desired depth region in the tire. A rectification mode is then selected, in this case -P, since the negative peak is the most prominent feature of a separation. The -P signal rises in a positive direction proportionately to any negative peaks within the gate, and remains at the largest amplitude reached until it is reset for the next transducer signal. In the B-planar display mode, this signal intensity-modulates the display as before but the brightness level is constant once the largest peak is reached, and the result is

Figure 14. Mode control panel.

Traces 1, 2: 20μs/cm
Traces 3, 4, 5: 3.2μs/cm
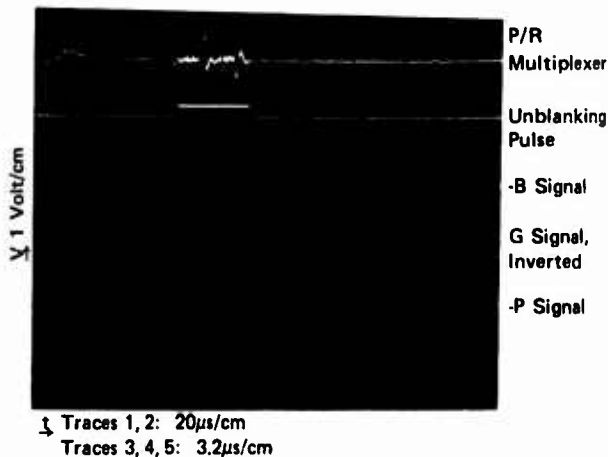
Figure 15. A-scope presentation showing processing options.

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as shown in Figure 16. The format is the same as for the B-scan display: each trace starts at the background level and then goes to a constant brightness level measuring the peak amplitude. The depth into the tire at which the peak amplitude is reached depends on the gate setting. Traces with early gate settings appear bright over much of their width while those with late gate settings are bright only at the right hand edge corresponding to the lower depths in the tire. If the C_A pushbutton is pressed, the C-Analog display mode is selected, and the peak amplitude is used to deflection modulate a trace for each transducer as shown in Figure 17. The shoulder separation appears prominently on the sixth trace at a position corresponding to approximately $\theta=135°$ on the scale. (The shift in θ-position resulted from operator error; normally registration is maintained for successive scans on the same tire.)

In the parlance of ultrasonic testing, both of the last illustrated displays are "C-scans." A single quantity is derived for each pulse measuring some attribute of the signal within a time window or gate, and this result is plotted in a two dimensional display, both axes of which correspond to mechanical coordinate. In our case the two axes of the display correspond to surface coordinates on the tire. The vertical coordinate being the θ-direction generated by rotation of the tire, while the horizontal axis is the ϕ-direction corresponding to transducer position around the cross section.

The final step in go-no-go evaluation of the signals is provided by the C_L-module which compares the selected output of the signal processor multiplexer with scan-programmed threshold settings, which of course can be different for each transducer. If the measured attribute of the signal exceeds the threshold, a saturation level output is generated which will print a white spot using the B-planar display, with the result shown in Figure 18. The shoulder separation on channel 7 (printed sixth from the left) which we have been examining, is clearly evident. In addition, a smaller separation is evident at approximately $\theta=45°$. This separation is evident on the plane B-scan on careful examination. Incidently, the solid white bars which go all the way across each B-scan strip on all of the B-planar displays are electronic artifacts. They are not present on channels having 0 values for θ-offset. The bright white spot at about 1/3 depth into the tire on the display for transducer 16 at about $\theta=90°$ is an artifact of the scan converter tube.

As has been illustrated by a number of examples, any of the processing options indicated by possible switch selections and multiplexer output choices indicated on the functional block diagram
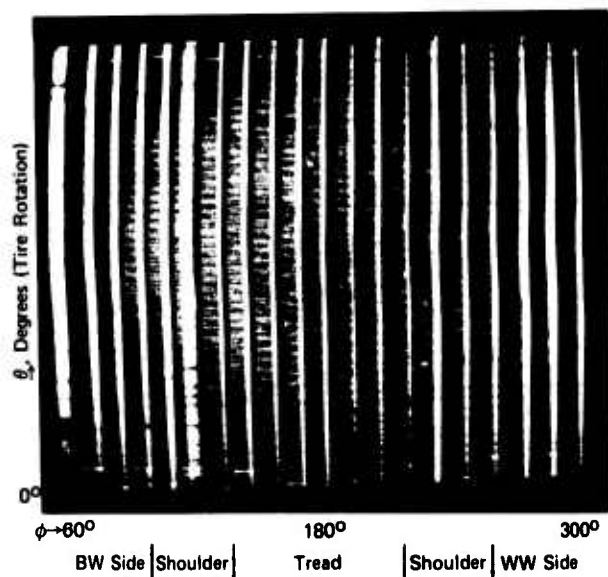
Figure 16. C-scan display - in B-planar display mode, gated and peak-rectified signal intensity modulates display.
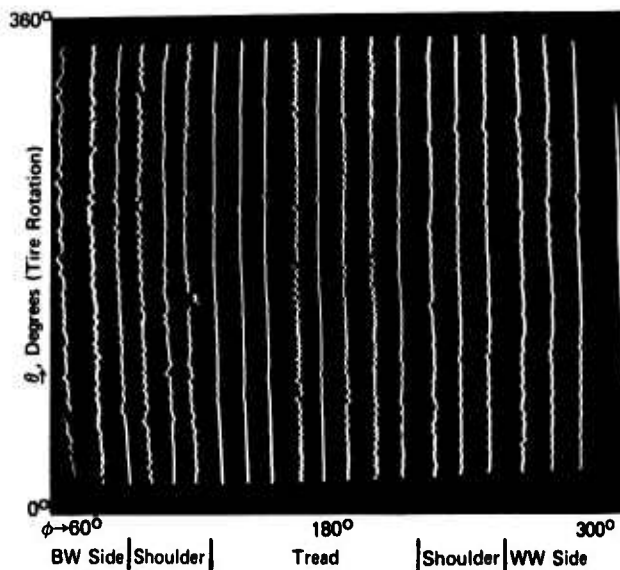
Figure 17. C-analoy display - Amplitudes of gated signals deflection-modulate traces.

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Figure 18. C-logic/B-planar display - Logic signal triggered whenever selected signal exceeds threshold intensity-modulates display.

can be used in combination with either of the display formats. The A-scope presentations for some more of the signal processing options are shown in Figures 19 and 22. The +H (positive half-wave rectified), the -H, and the FW (full wave rectified) outputs are intended primarily for enhanced B-scan displays. The B' signal is the original echo signal modified by programming the amplifier gain to increase exponentially, beginning at a certain onset time. The onset time (i.e., delay), the rate of increase, and a limiting value for the gain increase are all scan-programmable. As shown in Figure 20 this capability can be used to compensate for the attenuation which causes reflection amplitudes from the deeper ply layers to be smaller than for the outer layers. Besides enhancing a B-scan display, this provision is helpful in setting an automated detection threshold to be equally effective for defects at all depths. For this purpose the inner surface reflection, which is much larger than the levelled ply signals, would be excluded by the gate.

For automated detection of defects, one would generally want a measuring gate to cover that part of the reflection signal attributable to some particular structural element in the tire, for example, the outermost belt, the region between belts and body plies, the inner surface reflection, etc. While it is easy to set the gate delay and gate width so that any desired condition applies at a given spot on the tire, the amount of runout in tires is such that a setting made for one spot cannot be depended upon for the whole rotation of the tire. The usual answer to this problem in ultrasonic testing is what is called "first interface gating;" i.e.,

a timing signal is derived from the reflection from the first surface encountered in the tested object, and gate position is measured with respect to that signal. In the case of tires, this procedure appears undependable because in some cases there are serious variations in the thickness of some of the layers. Therefore, a range-tracking capability was specified in the design of this system. This permits a timing signal to be referenced to any prominent feature in the tire reflection signal, even to features which occur later than the timing signal itself. Actually, the time is referenced to the occurrence of the feature on the preceding pulse on the same transducer. This capability is implemented through a special digital processor which utilizes the resources of the digital control system. All of the signal processing time measurements are accomplished by counting cycles of a 20 MHz pulsed oscillator, which is started afresh with each main bang. A time to be measured, for example the Water Path Delay, is loaded as an initial setting for a counter which counts down at the 20 MHz rate. A timing pulse is generated when the counter reaches 0 and underflow occurs. The range-tracker processor establishes a trigger signal gate or window, adjustable in delay time (Range Tracker Window Delay) and width (RT Window Width). If the signal passes a threshold setting within this gate, a counter is stopped to measure the time of occurrence or "Feature Depth." The Feature Depth so determined is compared with the Feature Depth found on the preceding pulse, which was supplied from the parameter memory, and if the Feature Depth has changed, appropriate adjustments are made to the window position and to the range tracker trigger time by digital addition or subtraction, and the new values are stored back in the parameter memory until the same transducer is to be served again. Since the parameter memory at all times has stored the current values of the Feature Depth for each of the transducers, and since data paths from the parameter memory to the minicomputer are already established, we are very close here to a capability for digital acquisition of 24,000 dimensional measurements on the tire to any acoustically observable features within the tire structure.

But all of these considerations are related to efforts to apply automated defect recognition criteria of conventional gate-and-threshold techniques to defect detection in tires. Indeed, automated detection appears to be entirely practical for gross defects such as separations provided one optimizes the adjustments of time varied gain, gate positions, threshold heights, etc., to suit the particular type of tire being inspected. However, to detect possible anomalies which would perturb the normally present reflections, but which would not necessarily generate signals which rise above their average level, principal reliance must be placed at this time

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on operator evaluation of the B-scan display. This procedure is immensely aided by the zoom capability of the scan converter tube memory. A small region or window on the surface of the image storage electrode is scanned and the resulting signal is displayed full size on the TV monitor. With such electronic magnification, the resolution of the TV monitor contributes no limitation and the full resolution of the scan converter memory is obtained. Magnified displays of two regions selected from the previously presented scan are shown in Figures 21 and 22. Figure 21 shows the region in the neighborhood of the shoulder separation. It is evident that the separation extends to the next adjacent trace as well. Figure 22 shows the display in the vicinity of the bright spot in the channel 16 segment attributed to an artifact on the scan converter tube surface. A perfect tire would be at least rotationally symmetrical, and the display would show a series of vertical lines which would be completely straight and uniform. These displays show many instances of irregularity and modulation. Unfortunately a certain amount of irregularity must be considered normal, and we are still learning to relate anomalies in the displays to irregularities in the tire. Furthermore, a great deal of work still remains to be done to relate observable anomalies to tire performance.

We have seen that a large number of parameters must be set to define any sort of go-no-go test criteria or even to produce an optimized display for operator interpretation. Furthermore, all of these parameters have to be adjusted to suit the particular type of tire being inspected. The minicomputer installed in the system helps the operator to manage all of the parameter data. The actual scan-programmed digital control is all implemented in special hardware and the

system will operate without the computer. However, the computer accomplishes a very major reduction in the operator burden. The software is very elegantly designed to communicate with the operator through an alphanumeric video display and to guide the operator in the operation of the system. The "menu" of options shown in Figure 23 are displayed, and the operator makes his selection by keying in the appropriate option number and striking the "action" key on the keyboard. For example, option 1 transfers a parameter set from the hardware parameter memory to the computer memory. A basic purpose served here is that the computer memory is magnetic core, which is nonvolatile, that is, the stored data is retained even when the power is switched off, whereas the hardware memory is all electronic and hence is volatile. Option 6, "Modify Data Set From Keyboard," gives the tabular display we showed earlier in Figure 9. When the cursor on the display is placed to the left of a particular table entry the action key opens up space for a new line in the table and the operator can enter a new value or a plus or minus change. If the cursor is positioned all the way to the left at the label column, a keyboard entry will affect all 24 transducer channels in the same way, which provides a convenient way to make initial settings or global changes. A record of the settings used for any given test can easily be produced by copying the tabular display to the scan converter memory and thence to the hardcopy video printer. Options 3 and 4 provide for transferring parameter sets to and from paper tape. A modest addition of cassette tape or diskette peripherals would permit file-oriented storage of parameter sets, so that an operator would only have to key in an appropriate code to retrieve a data set prevoiusly arrived at for a particular type of tire. Besides loading the parameter set values, the computer can set standard or initial values for the α-angle alignment adjustments by outputting appropriate numbers of stepping motor counts for each channel. Coarse gain settings

Figure 19. Processor outputs for B-scan displays.

Figure 20. Time-varied gain.

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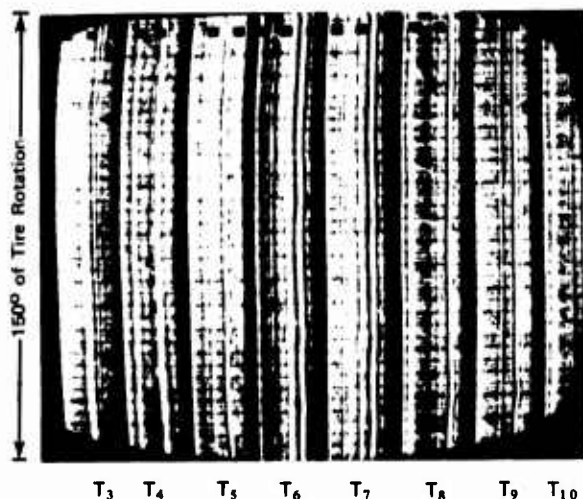
Figure 21. B-scan zoom display-#1 - Region of shoulder separation visible in Figure 12.

Figure 22. B-scan zoom display-#2 - Region in lower right of Figure 12. T_{13} shows an indication of a small separation between tread and body plies. T_{15} and T_{16} show perturbations of the inner surface traces suggesting possible separations, but probably caused by splices. The bright spot on T_{16} about 1/4 way from bottom is a display artifact.

made on the individual pulser-receivers cannot be set by the computer, but the settings made can be read by the computer and checked against the intended settings.

The general philosophy of the system design has been to recognize that while pulse-echo ultrasound provides a powerful capability for inspection of tires, it is inherently complicated by the complexity of internal structure and the unusual shape of tires. This basically geometrical complexity requires a rather complex setup to suit the individual tire before the full capabilities of the technique can be realized. In the system designed, the major burden of this complexity has been engineered into the system, and the operator has been relieved of as much of the routine bookkeeping as possible. Further, the use of digital control techniques permits the setup adjustments to be stored and re-used, so that the labor of arriving at them for various sizes and designs of tires need not be repeated. While this line of development has not been carried to the ultimate lengths that one might desire for production use, with a highly mixed population of tires, it has been carried far enough to be highly efficient for reasonably long runs of identical tires. For such runs, inspection times for the system as now implemented would be about two minutes per tire if the signals are merely acquired to video tape or processed to a single display for automated defect detection. Additional time would be added for real-time interpretation of the data displays, depending on the questions of interest and the degree of thoroughness desired. It is worth noting, however, that these inspection times are primarily limited by mechanical considerations. The ultrasonic limitation is to approximately

two seconds for the data acquisition scan. With totally automated interpretation, which is possible now if the rejection criteria can be made specific, a throughput of six tires per minute does not seem unreasonable for a highly automated ultrasonic tire inspection system.

Note: The machine was designed and built under contract by Teknekron, Inc., of Berkeley, California, in accordance with specific system concepts and performance specifications developed in preliminary work at TSC. Mechanical systems were sub-contracted to RF Systems of Cohassett, Mass. The work has been sponsored by the National Highway Traffic Safety Administration under a program administered by Mr. Manuel J. Lourenco.

QUESTIONS AND ANSWERS

Q: RPN (Rubber and Plastics News) talks about the NHTSA using an ultrasonic unit to find tire flaws, and they talk about a $10,000 system for recappers, or a more sophisticated system available for $75,000 that will take up to five tires a minute. Are they talking about your piece of equipment?
A: I think I invented the one you're talking about. I tend to agree that it is a rather optimistic price. The price for hardware has gone up and up. It is gone up a good bit from the time the contract was let to the time it was finished. The total development cost that we have into the machine now is about $250,000. One comment I would make on that, though, is what I'd

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Figure 23. Selection "menu" for programs to manipulate parameter set data.

like to call the till box analogy for ultrasonics. We built a machine here with the idea that we would look for "anomalies" in new tires which might be safety related. At the time we designed this machine, I say "designed" - of course it was designed under the government contract procurement procedure, and the spec was written which pretty much set the gross character of the thing.

The detail work was done by Teknekron in Berkeley, California, and the hanger was built in the Boston area, and they flushed all the detail over there. The point is that we put all our power into this with the idea that we would hunt for whatever anomalies might be detectable by ultrasonics in the hope that we would find those that were relevant to safety, and if someone could have told us 3 to 4 years ago exactly what we needed to find and could have assured us if we found it that would solve all the problems, then life would have been much simpler. So for industry people who are interested in a particular problem, remember that ultrasonics is not a tool but a tool box and there may not be the right wrenches in the tool box of this particular system to fit your problem, like in the transducer areas, because the specialization of what you've got is really in that area. On the other hand, there's possibly a lot more in this than is needed so more specialized machines could probably be made cheaper or more expensive - a great area for trade-off depending on just what power you want. If you want resolution for small spots, you can use small transducers, but it's going to take you longer to scan, so this little problem lies somewhere between too much and too little. Hopefully something will be useful.

PRODUCTION TIRE INSPECTION WITH X-RAY

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Since 1972 the tire industry has dictated the need for high production X-ray systems. Development and design has required automatic handling of the tires as well as automatic optimization of X-ray manipulator and X-ray components. To date, this has led to the design of machines, presently installed, with cycle times, per tire, of between 9 and 20 seconds per tire. Now for the benefit of those of you who are not familiar with X-ray systems, cycle time is defined as that period of handling time from initial input of the tire into the X-ray system until the tire is exited onto the takeoff conveyor. It is not inclusive of the inspection time. Even with the installation of twelve of these sophisticated automatic systems, and this does not include the numerous manual X-ray systems, we cannot guarantee an inspection time per tire over and above the cycle time. Visual inspection of the tire is dependent upon many uncontrolled variables:

1. The competency of the X-ray inspector.

2. Magnitude of inspection parameters. Bead-to-bead, belt only, sidewall only, degree of measurement per parameter, etc.

3. Inspection for production control or the unexpected problem that requires analysis and verification.

4. Operator fatigue.

5. The obvious - tire size.

6. Detail and contrast sensitivity of the cord material involved. Rayon, polyester, nylon, and Kevlar will not provide the contrast of steel.

As the years progress, we will be in a better position to more accurately guarantee inspection times per tire, but at the present time we can only promise cycle time and not total time of inspection.

Again, for the benefit of those not familiar with the X-ray systems available for production, please see Figure 1 for the heart of the AID system.
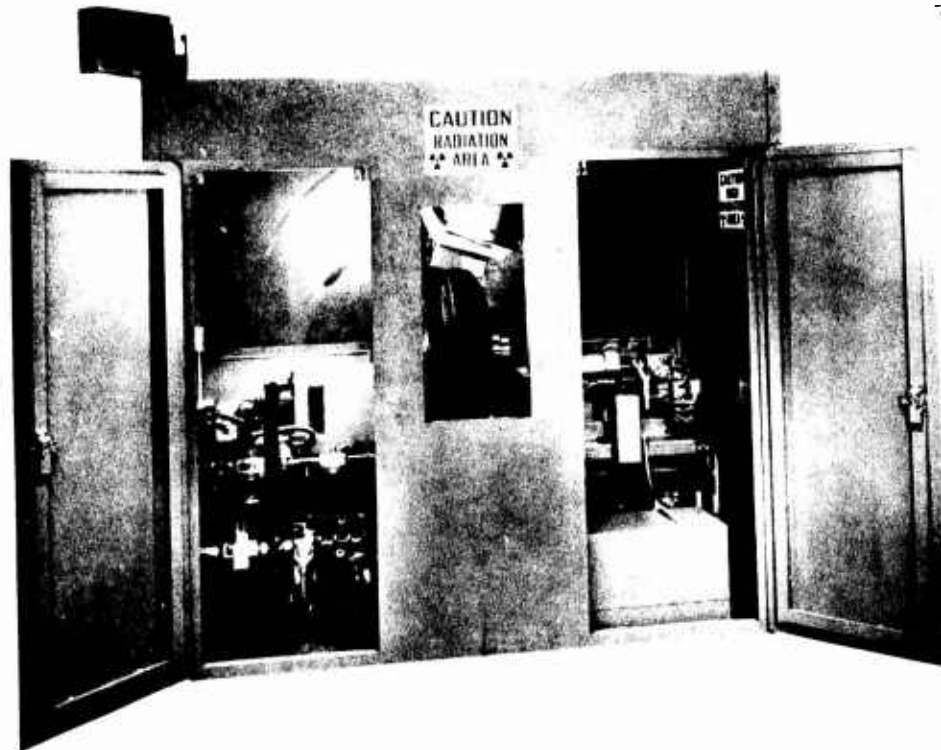
Figure 1

The AID air inflated device, Figures 2, 3, and 4 is a high production passenger/light truck system with a cycle time of 9 to 10 seconds per tire, inflated, with bead-to-bead capability, on all cord material. It uses fixed rims for mounting the tires. Tires are introduced into the overhead, horizontal acceptance chute, converted to the vertical acceptance input chute, released between the inflation rims, X-ray tube (Lighthouse-Picker patented) inserted, scanned from overhead, graded, and released to the lower roll-out take-away conveyor. The advantages to this system are the accuracies in mounting with air inflation resulting in precision measurements relative to tire component placement and symmetry simulating vehicle mounting. The disadvantage to this design is the lack of intermix capability. It must have a presorted input - in most cases, from the uniformity process.

Contrary to many established X-ray inspection techniques, an inflated tire can be inspected at a very high rotation rate - provided there is sufficient contrast as with steel and fiberglass constructions. With production inspection of tires, it appears that the majority of parameters of inspection are related to placement symmetry. To measure these changes it is necessary for the operator to be assisted with television monitor guidelines. High speed inspection is truly a process of comparison to the previous in three

modes - sidewall no. 1, tread and shoulder, sidewall no. 2. The human eye can measure these changes very accurately, assisted electronically, in motion, with a continuum of one tire area.

The 10/27/750 high production intermixed X-ray system, Figure 5, has gained significant acceptance within the last two years. The total system consists of six major components.

a. Input and sizing station
b. Radiation enclosure
c. Tire manipulator
d. Imaging system with "C" scan manipulator
e. Operator enclosure
f. Operator console
g. Electrical control station

The advantages of this system are the ability to randomly intermix tire bead diameters from 10-inch to 27-inch tires with automatic handling and scan positioning - bead-to-bead with only on X-ray tube and imaging system plus image all tire cord materials. In order to simulate the advantages of air inflation, such as the AID unit, and maintain as near accurate centerline of tire rotation, for component measurement, a split manipulator design was incorporated using four spindles from the top and four beneath. Tire rotation is accomplished by the driven spindles with no dependence on tread area. Spindle

Figure 2

60
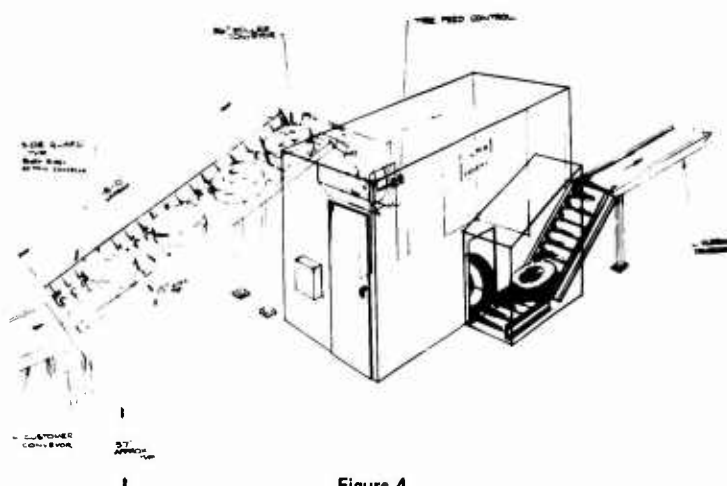
Figure 3

Figure 4

placement within the bead diameter is equidistant providing a uniform expansion to the rotation tire. Figures 6 to 12 show various close-up views of this system.

Why use a computer to control the intermix of tire sizes into the production X-ray system? Why not use a less expensive programmer? The advantages are many:

1. The computer will *simultaneously* adjust and optimize all system components to the intermixed tire system. It is *not* sequential resulting in reduced cycle times.

2. With the intermixed X-ray system, it is necessary for the tire manipulator, X-ray tube, and imaging system to optimize and position for maximum geometry performance. Over a wide range

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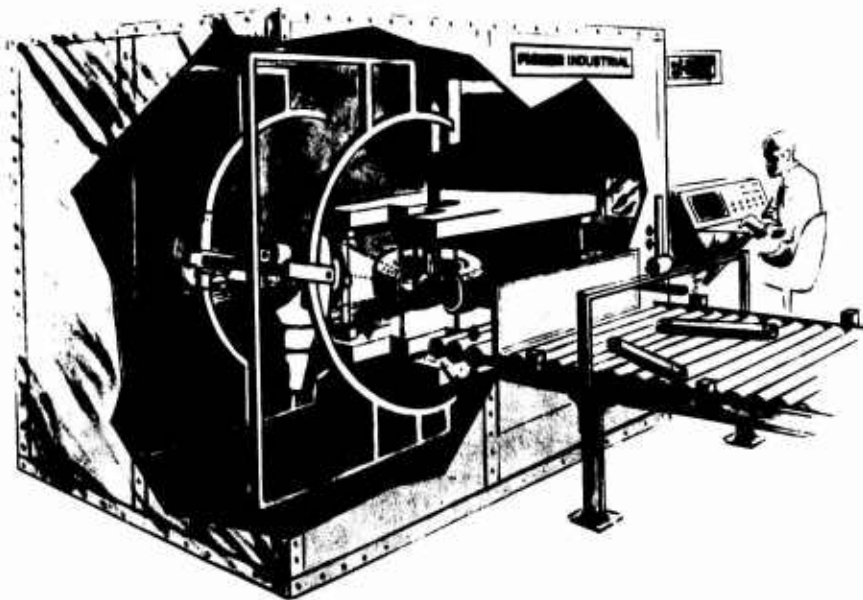
Figure 5

Figure 6

Figure 7

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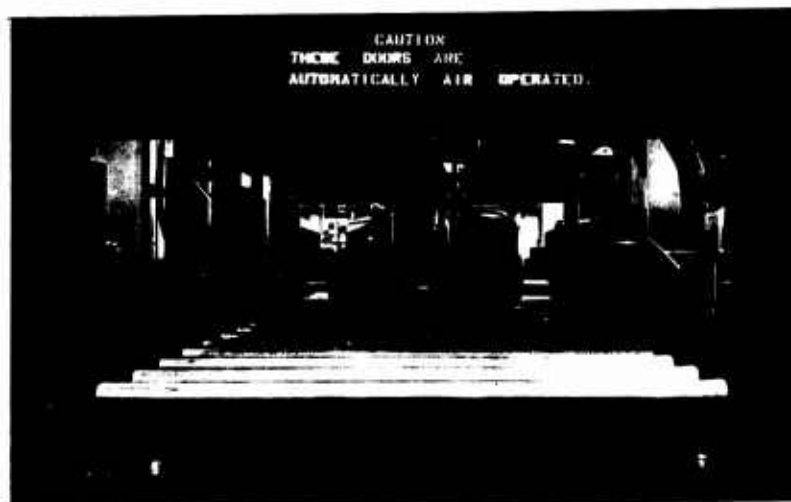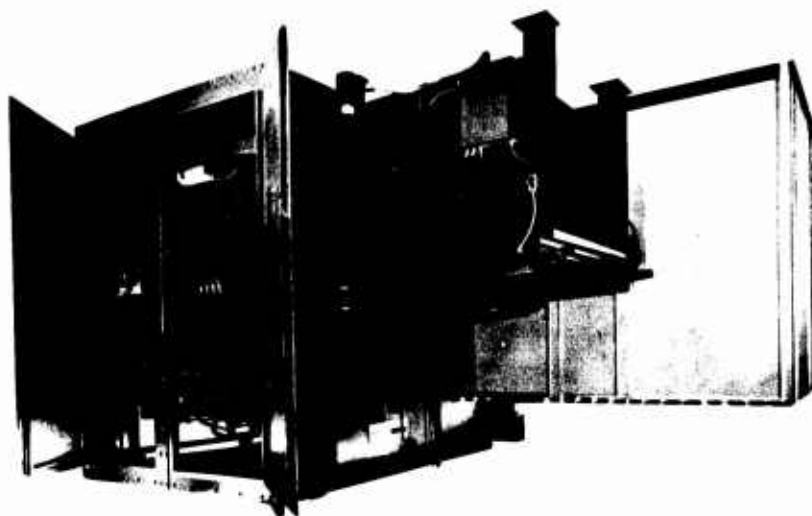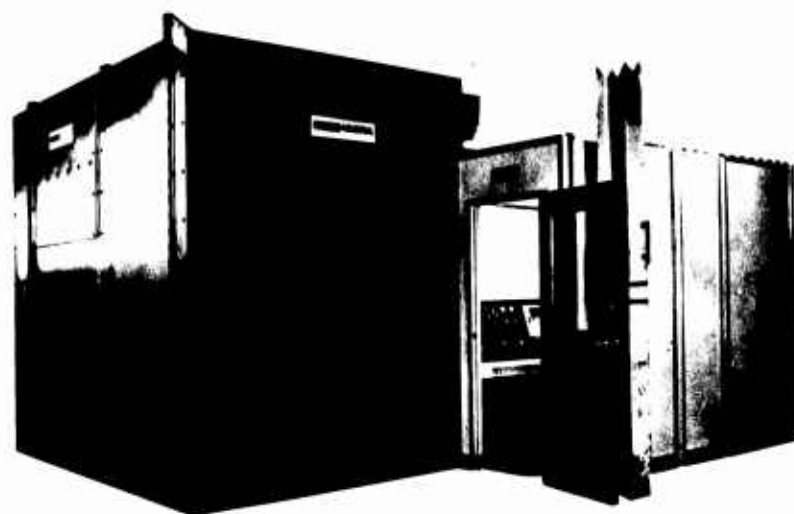
Figure 8

Figure 9

Figure 10

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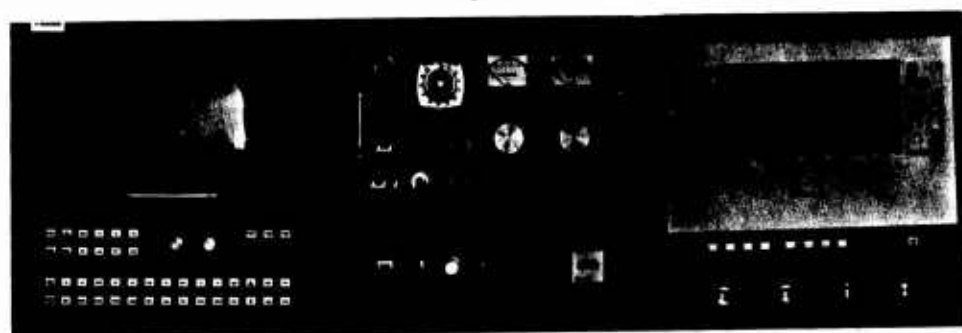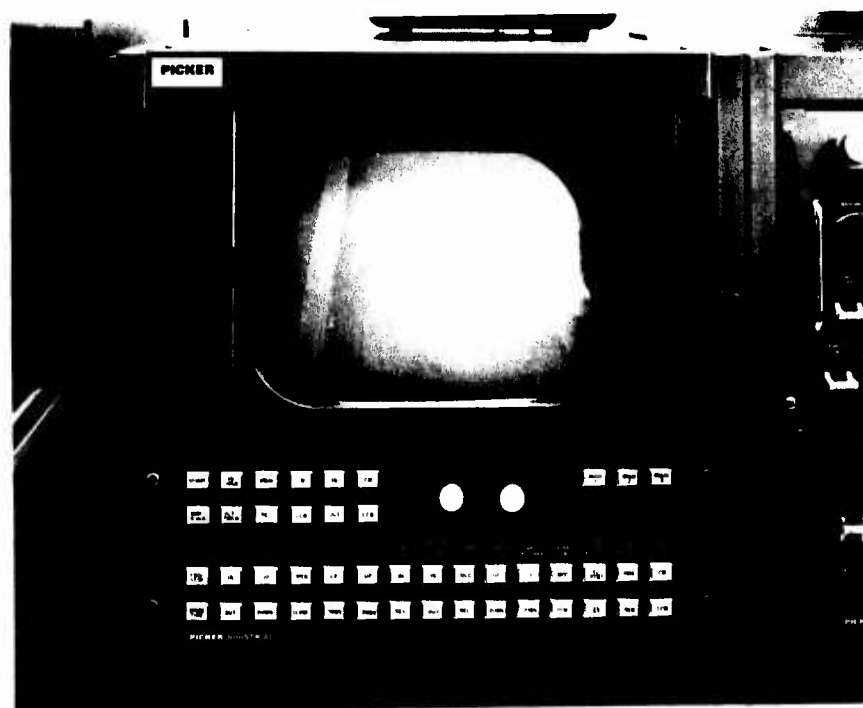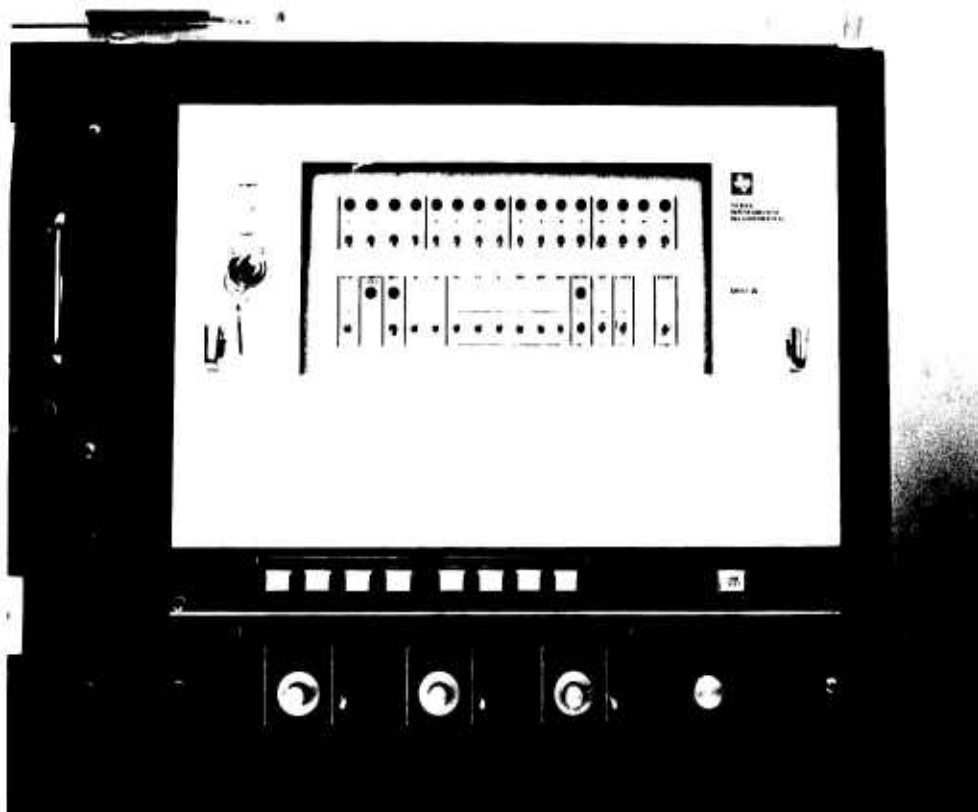
Figure 11

Figure 12

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of tires - from a 10-inch bead diameter to a large 27 inch - this requires a change in position of *all* the system components. Only a computer can respond to this vast and simultaneous storage problem. The high production intermixed X-ray system can not view the 10-inch tire with the same imaging and X-ray tube placement as with the maximum 27-inch tire. There are no compromises as with fixed position.

3. Programmed imaging scans per intermixed inspections can be accomplished. With selected programs the computer will conduct the entire inspection automatically. The only responsibility of the operator is to grade the tire. After the computer is told what tire is on the input conveyor sizing station, the tire is conveyed into the manipulator, mounted by eight spindles on the stable bead areas, spread, and the X-ray tube is stroked into the tire torus at the exact tire centerline and insertion depth. The tire then rotates at a preselected speed with the imaging system advancing to the optimized distance relative to the X-ray tube, and programmed step scans are made bead-to-bead. In addition to the programmed viewing scans, the computer can superimpose parameter/television guidelines to individual tire sidewall or belt areas per tire size and type.

4. With the in-line production X-ray systems, "downtime" should be minimal. The 10/27/750 production system computer uses the computer to maximum advantage by providing a fault system. The operator, in the manual scan mode of operation, is warned of collision or improper limits by means of an automatic binary lighted readout panel. The system is shut down until corrected, and the lead-thru panel lights provide guidance to remedy the fault. The operator is also directed to one of 125 subsystems as to component failure.

5. The computer can track, record, and identify tire inspection daily by data storage and readout.

In conclusion, I would like to thank the tire industry for making these X-ray systems available today. Without their design requisites, cooperation, and perseverance, we would not have the capability we do today. Hopefully, next year we will be able to announce the availability of a high production X-ray system, using the same handling systems but with signature analysis. If the human body can be scanned automatically with X-ray, and it presently is being done with computer assistance, let's apply that technology to our endeavor!

A NEW DYNAMIC FORCE AND MOMENT MEASURING MACHINE PRESENTATION AT THE THIRD SYMPOSIUM ON NONDESTRUCTIVE TESTING OF TIRES

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INTRODUCTION

For the past twenty years, researchers have been actively measuring the forces and moments generated by tires subjected to combinations of vertical load, slip angle, and camber angle.

Many design concepts have been attempted; and, today, there exist many machine configurations capable of generating such data.

These machines, however, were primarily designed to function in the laboratory environment and to generate data for research and development purposes. As tire force-moment properties and tire-vehicle interaction have evolved from research studies to well defined state-of-the-art parameters, the tire industry has new requirements for a machine system designed for production tire testing.

In 1974, Fabricated Machine Co. entered into a technical agreement with General Motors Proving Grounds relative the force-moment machine.

This formed the basis of the design of the continuous belt laboratory force-moment machine and the system we are discussing today, the FM 5000P Production Audit Force-Moment Measuring Machine.

The design criteria for the production audit machine include:

1. Continuous travel link belt roadway.
2. Capability to measure passenger and light truck tires.
3. Accuracies to 0.1% of full scale.
4. Capability of measuring lateral force and self-aligning torque.
5. Automatic control.
6. Computerized data reduction.

GENERAL

The FM 5000P Force and Moment System is composed of four integrated units; they are: flat belt-type road simulator, tire carriage and slip angle assembly, rigid main frame structure and integrated electronic unit. The flat belt is driven at a constant speed which is nominally two miles per hour. Dynamically controlled variables are normal (radial) force and slip angle. In addition to the controlled variables, lateral force and self-aligning torque are also measured and recorded. During each tire test, plots of lateral force versus normal force and aligning torque versus normal force are generated for all slip angles specified by the test. Calculated values for cornering coefficient, aligning torque coefficient, load transfer sensitivity, and load sensitivity are displayed on the CRT and printed.

Tire break-in and test procedure is conducted automatically in accordance with specifications entered by the operator prior to mounting each tire or group of tires.

The FM 5000P is designed specifically to provide high tire test throughput for production plant utilization. A cantilever spindle permits fast tire and wheel mounting and dismounting. A conversational program is incorporated to enable rapid break-in and test procedure set-up by the operator.

Complete machine calibration can be accomplished in a matter of two or three hours by means of proven calibration and linearization programs.

Accuracy, efficiency, and reliability compatable to the production environment are major features of the FM 5000P Force and Moment System.

Figures 1 and 2 show the general mechanical arrangement of the machine.

SPECIFICATIONS

Range

Normal Force	0 to 5,000 pounds
Lateral Force	0 to ± 4,000 pounds
Self-Aligning Torque	0 to 800 lb-ft
Slip Angle	0 to ± 6 degrees
Speed	2 MPH

Accuracy

Normal Force	5 pounds
Lateral Force	3 pounds
Self-Aligning Torque	1 lb-ft
Slip Angle	0.5 minute
Speed	0.1 MPH

Tire Size

Diameter	14" to 35" OD
Rolling Radius	6" to 17"
Section Width	15" maximum
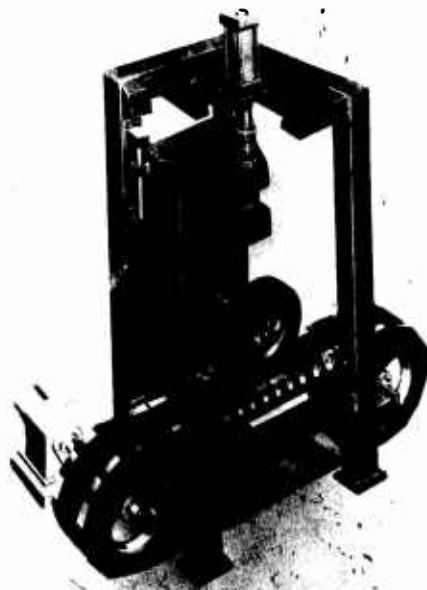
Figure 1

Figure 2

FLAT BELT ROAD SIMULATOR

A precision link belt is supported by two in-
flated 100 x 22.5 truck tires to form the road
simulator. Normal force applied to the test
specimen is transferred through the belt links
to a supporting roller assembly. Truck tire
axles and roller assembly are mounted on the main
frame structure. Link pivots are made with air-
craft needle bearings to insure long, troublefree
operation. Belt tensioning and drive friction
are adjusted by the truck tire inflation pressure.
An in-line helical gear reducer connects one
truck tire axle with a 50 HP AC motor. Gearing
is designed to produce 2 MPH linear velocity on
the belt when the drive motor is turning at 1,750
RPM. A tachometer generator provides a signal
for continuous display and recording. Precision
tolerances assure uniformity or roadway height
within 0.0015 inch.

MECHANICAL CONFIGURATION

Refer to Figure 2 for details of the following
mechanical configurations.

The carriage system is designed to input and
read out test tire vertical load, slip angle,
lateral force, and aligning torque with the
accuracies specified above.

This framework system limits the test tire to the
required number of degress of freedom to read out
and input required parameters.
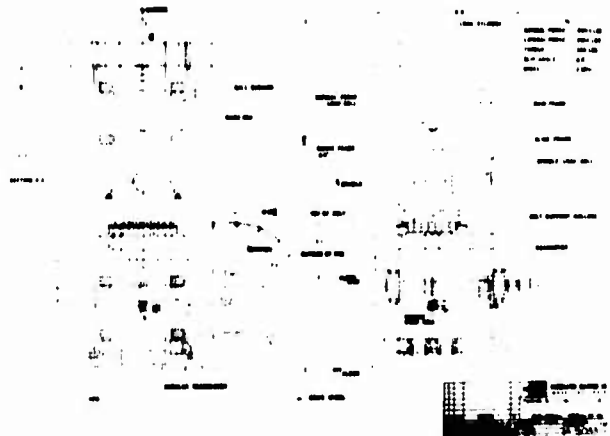
Vertical Load

Vertical load is input by an hydraulic cylinder
controlled by a servo valve feedback loop.

A precision electronic load cell between the
fixed frame and the vertical frame provides the
direct reading of tire vertical load and feedback
signal for the load control loop.

Thompson linear roundway bearings provide low
friction linear travel of the vertical carriage.
Precision alignment of the 60 case hardened ways
provides negligible friction of the linear bear-
ings and precision alignment typical of Fabricated
Machine Co. test dynamometers proven throughout
the world.

Slip Angle

A bell-crank mechanism inputs slip angle to pro-
grammed setpoints up to plus or minus six degrees
actuated by a hydraulic cylinder and servo valve
loop.

The slip angle is measured by a precision rotary
DCDT providing infinite resolution of slip angle
to the accuracy specified above.

A high-gain hydraulic servo loop assures the
accuracy of slip angle and provides adequate
force that setpoint slip angle is maintained
throughout a test regardless of variations in
vertical load or lateral force.

Precision hardened dowel holes between the ro-
tating frame and the vertical frame provide
calibration points at zero degrees and six de-
grees slip angle for calibration of slip angle.

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Lateral Force

A special hub-mounted load cell affixed directly to the subject tire spindle provides direct read-out of lateral force.

This system features a double flexture arrangement to resist deflections due to the subject tire's radial load but offers compliance in the lateral axis.

This load cell system was used originally on Fabricated Machine Co. laboratory dynamometers, and several units are in service around the world in similar applications.

Self-Aligning Torque

Direct reading of self-aligning torque is provided by a universal precision strain gage load cell mounted at the front of the hydraulic cylinder that actuates the slip angle carriage.

A linearization table in the computer compensates for any nonlinearity imposed by the bell-crank mechanism at the higher slip angles.

INTEGRATED ELECTRONICS UNIT

The Integrated Electronics Unit is primarily a digital computer system capable of operation in both on-line and off-line modes. This group of integrated hardware executes software programs in response to operator commands. Data acquisitions, servo loop control, data reductions, data storage, data display, and hard copy generation are produced by this system. Numerous calibration, linearization, and diagnostic programs are provided for simplified maintenance and verification procedures.

Figures 3 and 4 show the system design and console physical arrangement.
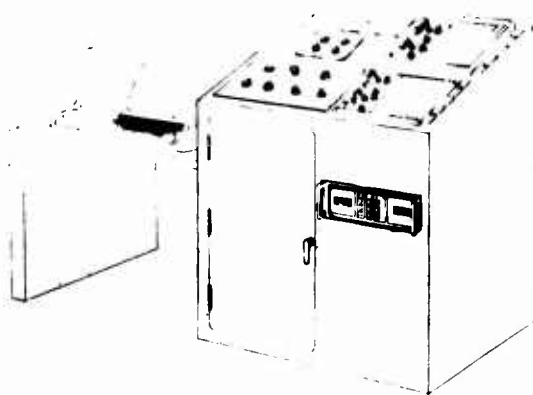
System Interface

The System Interface is a specially designed communication device that permits the computer to receive information from and transmit control commands to analog devices. This interface accepts analog signals from force and displacement transducers, amplifies each, then multiplexes and converts signals to digital values under program control. It accepts digital values from the computer and converts them to analog values to be used as setpoint signals in normal force and slip angle control. Additionally contained in the interface are analog output signals for the X-Y plotters and numerous switch and indicator inputs and outputs in discrete bit form.

System Software

In addition to the assembler, compiler, drivers, and utility programs normally supplied by the computer manufacturer, Fabricated Machine Co. provides special operating system software specifically written to satisfy requirements of the machine.

The Operator Executive program is the primary resident of the core memory. This program incorporates real-time clock, automatic power failure protection, and operator interaction routines. The Executive configures, sequences, and monitors current operating programs, mathematic programs and tables commonly used by other programs are also maintained as resident in core memory.

On-line programs are those that perform during test machine operations. Among these are:

Dynamic Filter - Designed to provide numeric signal conditioning for force signals as a function of tire rotation velocity.

Figure 3

Figure 4

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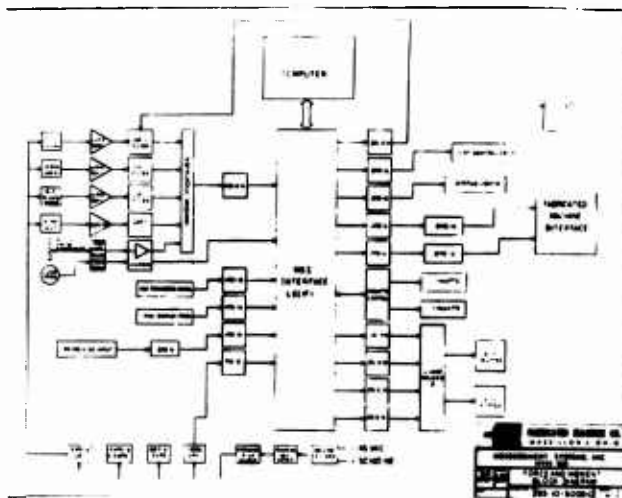
Linearization - A table look-up program designed to eliminate cross-talk from force cell readings.

Auto Zero - A program that compensates for any zero-drift or tire and wheel weight effects on force cells.

Loop Control - Provides supervisory servo loop control for normal force, slip angle, and road speed in response to measured and calculated values.

Data Display - Continuous updated display of measured test values.

Calibration - Forms look-up table during force-cell and transducer calibration with operator entered data from keyboard. Eliminates requirement for potentiometer adjustments.

Computer Functions

1. Radial force servo loop and acquisition
   Radial linearizer and calibration table

2. Slip angle servo loop and acquisition
   Angle calibration table

3. Lateral force acquisition
   Aligning linearizer and calibration table
   Radial to aligning cross-talk table
   Torque calculation

4. Self-aligning "force" acquisition
   Aligning linearizer and calibration table
   Radial to aligning cross-talk table
   Torque calculation

5. Raw data display

6. Radial calibration

7. Lateral calibration

8. Aligning calibration

9. Slip angle calibration

10. Calibration table print

11. Calibration table punch

12. Calibration table read

13. Tare values print

14. Heading data entry/print

15. Break-in specification

16. Test specification

17. Result

DATA RESULTS

Plotted Real Time

1. Lateral force versus normal force
2. Aligning torque versus normal force

Computed, Displayed, and Printed

1. Cornering coefficient at 1° slip
2. Aligning torque coefficient at 1° slip
3. Load transfer sensitivity at 4° slip
4. Load sensitivity at 1° slip
5. Accuracy of calculated curve fit versus raw data

X-Y Plots

The control console includes two X-Y plotters for real-time plotting of lateral force versus vertical load and self-sligning torque versus vertical load simultaneously.

This assures the operator of proper functioning of the mechanical and electrical portions of the machine exclusive of the computer manipulation.

Also, the operator at a later date can spot check the computed values by hand calculations based on these plots.

CRT Display

The control console includes real-time CRT display of vertical load in pounds, slip angle in hundredths of a degree, lateral force in pounds, and self-aligning torque in foot pounds.

This data gives the operator a backup of real-time functioning of the machine and also is used for calibration assistance.

Computed values are also displayed on the CRT as described below.

In setting up the machine, the operator calls up the schedule page from the keyboard and inputs the normalizing load and the warmup cycle prior to individual tires being run.

Then the operator has the freedom to leave the machine for automatic warmup and test cycle while he mounts the next tire in sequence for testing.

Computed Values

The computer makes a best spline bicubic fit of the raw data and stores for computation purposes the coefficients required for the above calculations and displays.

At the conclusion of the computation, the four characterizing functions are displayed on the CRT plus the accuracy of the fits including the maximum and the average difference of the computed fits versus the raw data.

Figure 5 shows a hard copy of the CRT display which is printed for each test tire.

CALIBRATION

Radial Load and Lateral Force

Radial load and lateral force are calibrated by loading a subject tire onto the Fabricated Machine air bearing-supported, standard, dual-axis calibration plate, which is supported by the flat bed itself. Figure 6 shows this device.

This unit includes precision electronic load cells oriented and instrumented to give direct digital readout of tire radial load and lateral force. The unit is delivered calibrated traceable to NBS standards in both axes, including internal precision self-calibration check.
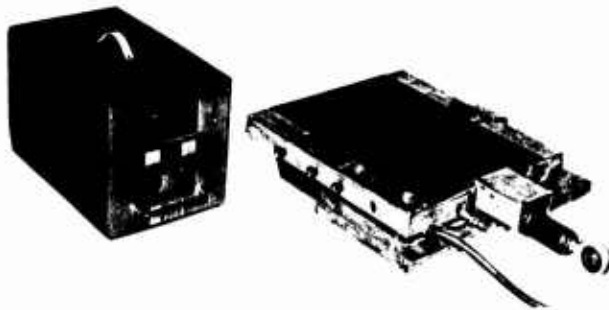
Both machine radial load cell and lateral hub-mounted load cell are, therefore, calibrated with this device as a standard.

Using the calibration mode and the CRT calibration table, several calibration points between zero and full span on both of these load cells are entered into the computer lookup table to compensate for nonlinearity and cross-talk in the load cells.

Slip Angle

As described above, precision dowel holes in the fixed frame and the rotating frame are aligned and bored at the factory on assembly of each machine to provide a fixed calibration point at zero degrees and ± 6° of slip angle.

Intermediate points are established by the computer based on a fixed lookup table which compensates for nonlinearities at the high slip angles due to geometry of the bell-crank mechanism.

Self-Aligning Torque

The self-aligning torque load cell of the FM 5000P is calibrated by a precision calibration load kit including electronic load cell and matched electronics which are delivered as a unit traceable to Bureau standards.

The machine framework is designed to accomodate fixturing of the calibration load cell between the actuating cylinder of the self-aligning torque load cell and the machine fixed framework.

Figure 5

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DEFECT SIZE CRITICALITY STUDY IN NAVY AIRCRAFT TIRES

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Presented by
Larry Klaasen
Naval Air Research Facility

INTRODUCTION

The purpose of the study was to determine the criticality of defects in Navy aircraft tires. The Navy is very interested in propagation of anomalies, because of the nature of the aircraft flown. For the most part, the aircraft have a single tire on each main landing gear, so if the tire fails, there is possibility of damage to the wheel and MLG system, FOD to wings and fuselage, and the possibility of losing the aircraft, and pilots. The Navy aircraft tires are exposed to a more hostile environment than aircraft in the other services or the commercial sector, in particular, the requirement for catapult launches and carrier landings, more aptly called a controlled crash. Also, there are multiple arrest cables, 1-3/8 inches diameter, which are crossed during landing and taxiing.

Therefore, this study becomes very important if it prevents the loss of one aircraft due to a faulty tire. The defects to be examined are separations or disbonds as determined by holographic nondestructive testing. It is an accepted general knowledge that separations in an aircraft tire will propagate. We wanted to know the criticality of these propagations: how fast will the separations grow, at what size will the separations be detrimental to the tire integrity, and if there are locations in the tire where separations are more critical.

EXPERIMENTAL

The tires used in this study are 26 x 6.6/16PR Type VII Navy aircraft tires. These are the main landing gear tires on the Navy's F-8. The tire is usually constructed with a reinforced tread, the exact design of course varies with each manufacturer. The tire studied has two tread reinforcing plies approximately half-way between the bottom of the grooves and the carcass plies. The tires were obtained through the regular supply system or were rejects from a Navy contracted rebuilder. All of the separations or defects were "natural," arising from the manufacture of the tires, and were not intentionally made.

The tires were inspected with an Industrial Holographics tire analyzer which was equipped with a krypton laser. The tires were hologramed and a map of the separations was made for each tire. As each tire was hologramed at a later date, the same map was used and the separations were recorded along with the earlier runs, so as to more easily see trend development.

After mapping the separations, the tires were sent to Wright-Patterson AFB (WPAFB) to be tested on the dynamometer. The test run on the dynamometer consisted only of a taxi-take-off cycle as used by the Navy in Military Standards 26533 and 3383. This test consists of a taxi for 10,000 feet at 23 mph and 12,000 pounds. The tire is stopped and run through a take-off consisting of from 0 to 200 mph in about 7,300 feet and loaded initially at 12,000 lb, and decreasing to 1,200 lb at lift-off. The requirements are for the tires to complete 50 cycles of Test A under these specifications.

The procedure was to initially plot the separations, the tires were then sent to WPAFB and a series of 5 taxi-take-off cycles were run. The tires were returned, re-hologramed, anomalies plotted, and returned to the dynamometer. This was continued for approximately 20 cycles with holograms every 5 cycles or until the tire failed. Those tires that have survived so far are now being run to failure.

RESULTS

I wish to show three examples of tires that have been tested and the propagation of anomalies within the tires.

1. The test report included a chart used for recording the separations. There are four 90° quadrants starting with the S/N at 0° and proceeding around the tire to 360° at the S/N again. The area plotted is from sidewall to sidewall.

The first tire, N10, showed some very large separations in the initial hologram (in H_0 on Figure 1). At this point the tire had not been run on the dynamometer. The separations varied from 1/2 to 3 inches long and most occur along the shoulder of the tire. The depth of the separation was not known. It could be at the reinforcing ply, undertread, or in the carcass.

After a series of 5 taxi-take-offs, the individual separations have merged into several large separations, almost one continuous separation (in H_2 on Figure 1).

During the next series of taxi-take-offs, the tire failed, completely throwing the tread, (H_2 of Figure 1).

The Military Specifications require 50 cycles for the tire to pass. This tire went less than 10 cycles. If it had been on a F-8, the least it would have caused is premature tire change, a loss of maintenance manhours, and placing the aircraft in a down status.

2. The next example, N8, showed only one separation initially. This separation was approximately 3/4 inch diameter and located near the center of the tread. See Figure 2 at 235 degrees. The depth of the separation was unknown.

After the first series of dynamometer runs, the initial separation had not grown, but the tire had developed three new separations of 3/8 inch diameter located in the center of the tread (in H_2 on Figure 2).

After 10 cycles, the initial separation had grown to 1 inch and the other separations had grown to 3/4 inch and 1 inch size (in H_2 on Figure 2).

The results were not available to plot the separations after the 15th and 20th cycles. After the 20th cycle the tire was run to failure, which occurred on the 28th taxi-take-off cycle.

3. For the last example, N4, the tire showed some very small separations in the tread area, overall a relatively clean tire (Figure 3).

After a series of 5 taxi-take-offs the separations had not grown but the tire had developed several small separations in the shoulder ranging from 1/8 inch diameter (in H_1 on Figure 3). It developed an area in the opposite shoulder that is characterized as weak but did not show any actual separations in it.

This tire then failed before the 15th cycle of taxi-take-offs, throwing the tread.

Figure 1

Figure 2

Customer	Tire O R		Size	House Number
NAVY	Special Study	✔	26x6.6	N4
	Reject			
Mileage	Retread Number	Carrier In		Serial Number
6 Taxi Takeoffs				
		Out		
Date Received	Date Shipped	Shipper Number		Hologram Number And Date
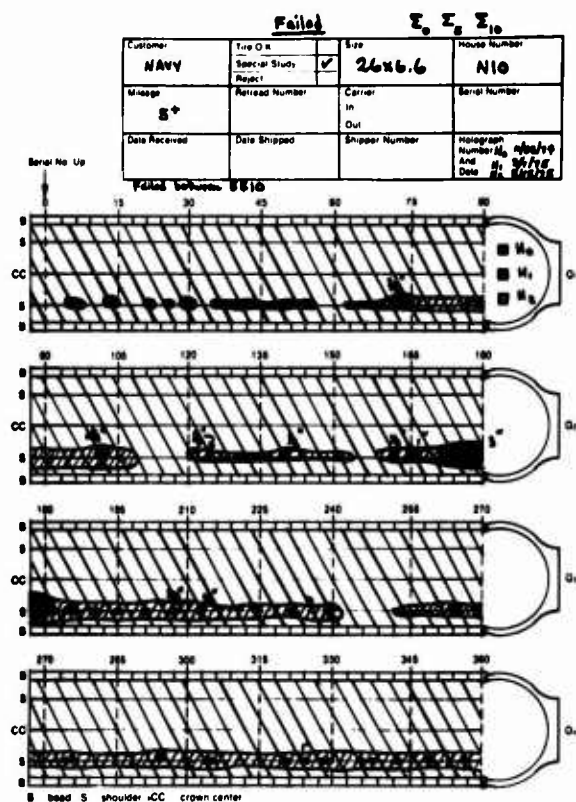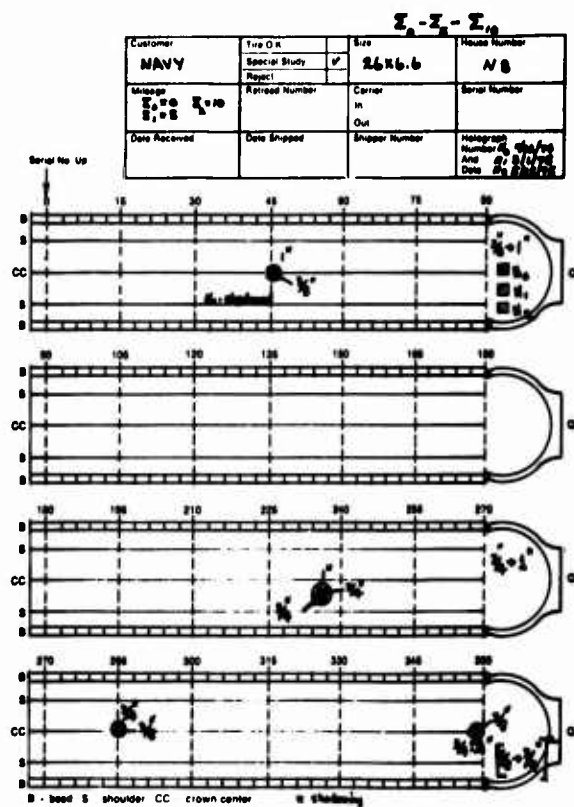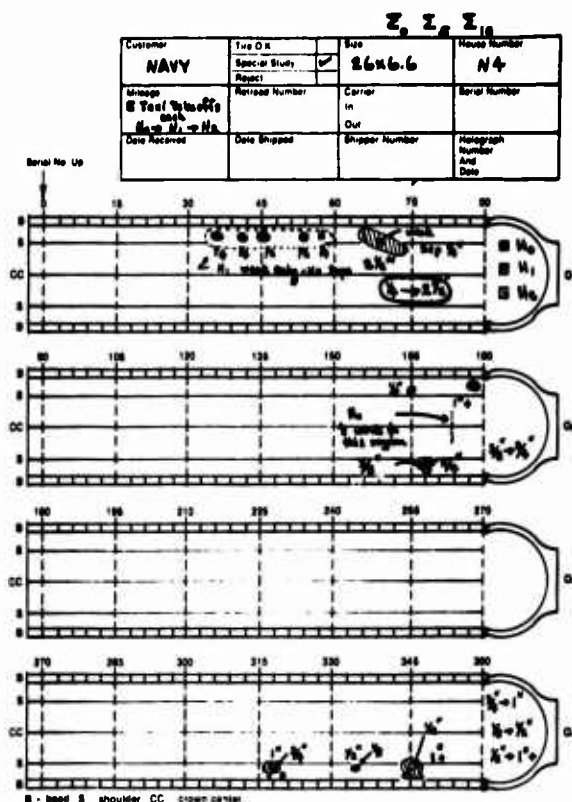
Figure 3

CONCLUSION AND SUMMARY

To summarize the results obtained thus far, there is a maximum size separation that the tire can handle.

We see 4-inch separations fail within the next series of 5 taxi-take-offs, 3-inch separations grew larger and then failed in 10 cycles; a 2-1/2-inch separation fail in the next 5 cycles, and a 1-1/2-inch separation grew to 4 inches and fail within 10 cycles. The failures resulted in a complete loss of the tread.

Thus, we see that the size of approximately 3 inches will cause a failure in very short time on the dynamometer.

We have seen what happens to the tires containing large separations. The following description is of some of the smaller separations.

We saw the separations grow during a 5 cycle series from 1/8 inch to 1/2 inch, 1/2 inch to 1 inch, 3/8 inch to 3/4 inch, 1 inch to 2 inches. In one case the separation grew at a slower rate, a 1-inch separation grew to 1-1/4 inches then to 1-3/4 inches after 10 cycles.

We observed that the small separations enlarge at a fairly rapid rate on the dynamometer. Thus far, any tire with a separation in it, could be expected to fail.

As I have mentioned, this study is approaching its conclusion. The results presented were an initial view of some of the early work. The tires are now being run to failure on the dynamometer, and final analysis of the tires will be performed to determine the cause of the failures and the depth of the separations.

I wish to thank Dr. Grant, Industrial Holographics, for the NDI work; CAPT. Larry Wilder, Wright-Patterson AFB, for the dynamometer testing; and Gwynn McConnell, Naval Air Development Center, for their contribution in this study.

QUESTIONS AND ANSWERS

Q: Where were your dynamometer failures related to these holographic separations?
A: I didn't quite understand the question.
Q: Were you able to trace the failures back? Were they directly related?
A: We haven't had a chance yet to examine all of the tires with the exact location. I have made a preliminary inspection of some of the failures and they appear to be related to some of the major separations, but the exact locations I don't know yet.
Q: Do you know that these were separations in the first place and not just the tire based on your experience of reading holograms?
A: Yes. Separations were determined from previous experience to be there and the sizes of them were verified by cutting up the tires and actually looking at the separations.
Q: What is the time between cycles on the dynamometer when you are stopped for a cool-down?
A: I don't know.
Q: Can you tell me about the defects that you have have uncovered; did they all grow or did any defects not grow?
A: The defects that we're looking at have all shown growth on the dynamometer. The tires presently are being inspected after rebuilding, and we don't have the inspecting pressure on used tires that we have on the new tires.
Q: Is it possible that a location of a separation can vary in importance?
A: That is a possibility. Another reason for the study was the criticality as to location of the defect. Now this particular tire has reinforcing plies. A lot of defects occurred at what appeared to be the shoulder area or at the edge of the reinforcing plot. On the dynamometer, it is felt that it would stress more at the edge of the reinforcing part. It may have different growth factors depending upon where the separation is.

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THE STRUCTURAL INTEGRITY AND UNIFORMITY OF AIRCRAFT
TIRES AS OBSERVED BY HOLOGRAPHY

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This discussion is predominately on the subject of structural integrity and structural uniformity of aircraft tires with some comparisons made on truck tires.

Much of the work we have been doing on aircraft tires is extremely preliminary. We have tested only a few thousand to date. Normally our testing facility tests about 20 to 40 tons per month. We have learned rather painfully from mistakes which we have made testing truck tires in past years, that it takes a very large data base over an extended period of time before one can establish with any degree of credibility exactly what is taking place in terms of specific failure mechanisms. Our basic objective is an understanding of the life expectancy or durability of a tire. How does one get his money's worth out of a tire? How, basically, does it fail, and when is it going to fail? In the case of truck tires, we look at the diameter of a given separation in a tire as a function of the mileage. We follow a given tire up to 160,000 miles. For example, a quarter inch wide separation in a new radial truck tire will grow linearly as a function of mileage up to typically one or more inches within 100,000 miles. We plot the separation diameter as a function of mileage through repeated tests at various mileage points. We then observe the size of the separation just prior to the failure point. We note, within the limits of statistical error, that in general there is a linear relationship between separation size and mileage, which almost always results in separation propagation which is quite predictable in other tires of identical construction under similar road and load conditions.

Now, let us return to our discussion of aircraft tires. If you want a good dose of humility in terms of studying failure mechanisms in tires, just move from truck tire studies to aircraft tire studies. Aircraft studies are much more difficult. The initial sample of a given size of new R-0 tires typicall have few separations in them, 1% or 2% on the average, 3% or 4% at the most. However, after watching them beyond R-1, the first recap level, or R-2, the second recap, we will sometimes see separations suddenly appear along with a progression of poor structural uniformity in the tire. Separation will propagate at a fairly slow rate for a period of time, and then suddenly propagate almost exponentially into a quick and sudden failure. Instead

of having the linear separation propagation relationship which we observe in the case of a typical truck tire with good uniform strength, we will have a situation where we may see relatively slow propagation of separation over an extended period of time which then abruptly leads into sudden separation growth as the number of landings proceed. In a typical aircraft tire, we will see a small separation sit idly by, propagating very slowly as the number of landings progress, then all of a sudden it will propagate to failure over a relatively short number of landings. Aircraft tires are complex because the propagation mechanism is critically influenced by the overall structural strength or structural uniformity of the carcass. That is, a small separation in a weak carcass may propagate very fast, but a moderately sized separation in a very strong carcass will propagate very slowly and go through a surprising number of R levels before it will lead to a terminal failure.

The result in aircraft tires is that the stretch or the elongation as a function of applied load which gives us the most significant data, as opposed to the classical mechanics case for homogeneous metals where strain data which is measured as a function of applied stress, provides us with the best information. Life is basically simple in a homogeneous metallurgical situation, a one dimensional problem where you can pull on the material with a given applied stress in pounds per square inch and measure out the corresponding strain in inches per inch. Holographic testing does not provide us with strain data directly, but rather gives us the overall stretch or elongation characteristics of the carcass for a given applied load. This type of data turns out to be exactly what we need, since it reveals the general strength characteristics of the tire.

Briefly, we might note that holography is a laser photographic process which can photographically record a three dimensional view of the tire. Employing as a test method the combination of holography and interferometry, minute displacements can be measured in three dimensional objects. In the case of a tire system, it is absolutely essential to look at the complete three dimensional object, rather than gathering data at a single point which is the typical case for metals. In a tire, the comparison between relative rather than absolute data points is crucial to the strength of materials analysis. The

measurement of minute displacements in tires as a result of an applied load can lead to judgments about the quality of a tire.

Let us look at the following simple analogy which will help us to understand the manner in which we obtain the final data. Suppose we had a thinly stretched rubber membrane of which we had taken a three dimensional hologram. (A hologram is a special type of photograph taken with a laser beam.) We could then set up a very simple interferometer and look at that membrane after we had made the hologram. Then we could put our finger behind the membrane and push it very gently forward. The image that we would see as we push that membrane out would consist of rings or concentric circles which would be contours of constant displacement. As we push the membrane out, we could then generate a contour map (the contour lines on the map would represent levels of constant displacement or levels of constant heights above a reference) which would tell us the general displacement from the original position. Now in terms of a tire, we want to see the overall displacement between the unstressed and the stressed tire carcass. In reality, what we are trying to do is just set up a three dimensional stress-strain measurement where we can read the relative stretch or displacement out in the form of a simple image as a result of an applied stress. It is of crucial importance that we obtain our data over a region of the tire's surface as opposed to obtaining data at a single point in space which was the case prior to holographic interferometry. In a holographic tire testing machine, we take a photograph or a hologram of an interior region of a tire, say for example, a left to right view from 0° to 90° and a top to bottom view covering the tire from the top bead to the bottom bead as viewed from the center of the tire. If we take a second exposure on the same film plane of the interior of the tire after we have applied a stress, which can be done by putting the tire in a vacuum, we come up with a contour map that represents to us the stretch that is produced as a result of the applied stress.

To get the tire ready for testing, metal spreaders are put into the interior to hold the beads far enough apart to enable the camera to view the entire interior of the tire. The tire is then ready to be placed into the holographic machine on a merry-go-round turntable assembly under a vacuum dome. The tire surrounds the interferometric camera which takes the hologram. Ninety (90) to 120 circumferential degrees are automatically viewed at a time. The tire is holographed (or photographed) both with and without an applied vacuum to obtain the relative stretch caused by the applied stress. The tire is then rotated to the next 90 or 120 degree view, etc. Typical test time for a tire for the type of results we will be discussing is about two minutes.

In most of the tires which we test, we obtain an upper mid-sidewall to lower mid-sidewall view. In a few cases, we insert mirror assemblies to provide bead-toe-to-bead-toe views.

Now let us come back very briefly to the method. If you were to take an object and put it in a vacuum, that object being a multiple ply tire, the overall tire being tested would dilate, stretch, or elongate as a result of the applied vacuum. Our camera would record a background fringe pattern which would relate to us how the tire surface moves or stretches topographically.

In a situation where there is an interply separation inside the structure, not only do we get this displacement as a result of having put a negative pressure on the surface, hence lifting the entire surface; but there is also an added displacement as a result of the air expansion inside the void or interply separation. Whenever we observe the concentric ring pattern of a separation, it has a background fringe structure surrounding the separation which tells us the relative strength of that region, in addition to the fundamental pattern which reveals the void or separation itself. So, in summary, we observe a background displacement pattern as well as a displacement pattern which is associated with any separation, or lack of structural integrity.

Next let us explore this background pattern which reveals the general strength of the tire. For example, if we look momentarily at the turn-up region or the flipper edge of the tire and rotated the tire circumferentially (reference your observation point as being at the center of the inside of the tire) and assume that the tire's internal construction geometry remains the same within very close tolerances, as does the relative strength in that region; we will then note in the hologram that the fringe lines are always uniform and very beautifully behaved. If the geometrical components inside the tire are straight and geometrically symmetric, the fringe lines or contour lines will be geometrically symmetric. The tire has stretched uniformly due to the geometrically symmetric construction detail. In other words, the fringe lines merely correspond to the stretch nature of the tire. Had there been an interply separation in the tire it would have exhibited itself with its own characteristic pattern which is a direct measure of its given size. If the separation is close to the surface, with respect to the observer, there will be a larger bulge and consequently a larger number of fringes. If the separation is deep or farther away from the observer (near the tread), there will be fewer circular fringes or concentric circles. Consequently, we can resolve the general position of the separation in the structure as well as determine its relative depth in the tire. As you look from left to right, parallel to the bead, you will notice that the

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fringes are extremely linear and horizontal. If you take a tire in your hands and rotate it around your head circumferentially (with your head at the center of the tire), wherever you look circumferentially (assuming you have X-ray vision), it should be the same geometrically. On the other hand, if you observe the tire in the radial direction, there are different cross-sectional thicknesses, different strengths, and therefore the fringe spacing is different. Hence from the above comments, all holographic fringes (aside from the pattern caused from changes due to variations in the index of refraction during the measurement which enhances the read-out) run horizontally from left to right and have different spacing up and down. Now what would happen if we had a tire where there were variations in the height, say at the turn-up? This variation could lead to a variation in the strength. Then instead of the classic very uniform linear horizontal fringes, we would see fringes which wander up and down as we move circumferentially around the tire. This would mean that we are getting a different magnitude of stretch as we move circumferentially around the tire.

When a tire is constructed with near perfect geometrical proportions and such exacting geometry is further coupled with near perfect adhesion throughout, the fringe pattern will be highly uniform. This happens because the tire carcass responds, stretches, or elongates due to the applied load or stress induced by the vacuum in a highly regular or uniform manner. In other words, if the strength of the tire is uniformly symmetric, the fringe pattern will be uniform. In a highly uniform tire, we find the separation rate propagating more slowly than in the non-uniform tires. Higher shear stresses as well as higher temperatures develop in nonuniform tires resulting in the higher propagation rates. For example, a quarter inch separation in a 40 x 14 aircraft tire will go through 200 or 300 cycles or landings before propagating significantly if it is in a very strong carcass. If, on the other hand, it is in a very weak carcass as revealed by nonuniform fringe contour lines, it may propagate to failure within 25 to 50 cycles, especially if it is in the shoulder region. If the background fringe pattern is geometrically nonuniform, cord tension will vary over a greater range and fatigue will set in much faster. Separations will evolve more readily and will propagate at a higher rate. If however, the background fringe pattern is uniform, separations will only rarely appear over the first hundred cycles; and when they do, they will propagate much more slowly. Hence in aircraft tires, it is particularly important to take this background structural uniformity into account when predicting the rate of propagation of a given separation

at a given location. The performance characteristics of a given tire construction will be critically dependent upon the observed state of the tire's structural integrity.

In summary, it should be noted that a large structural uniformity data base must be established before a realistic acceptance-rejection criteria can be established on a given type of tire. The existance and size of a separation is not nearly as important an observation as the overall structural uniformity, unless of course the separation is well over an inch in diameter and it is in a critical geometrical position. One must always judge the criticality of the size of a given separation as a function of the observed carcass strength which is revealed by this general structural uniformity.

Now there are some basic questions at this stage which we should begin to ask ourselves. What is the incidence of interply separation in a typical sample of aircraft tires? Given the fact that they exist in a given structure, what is the probability of failure during the original tread life: R-0, or R-1: the first recap level, or R-2: the second recap level, etc. In general, there are fewer separations in aircraft tires than most of us realize. It turns out however in a few isolated cases, that abnormal outcropping of separations in given tire sizes do exist as a result of construction mistakes, poor workmanship, contamination, etc. Often modest changes in tire construction can reduce separation problems.

One of the most common causes of separation in new tires is due to the existence of pieces of "poly" left in the tire when these protective sheets are pulled off the original stock material during the building of the tire. An example of dealing with separation problems by changing construction details in 40 x 14's is to reduce cord diameter and increase skim coat thicknesses to provide greater insulation between plies. In one particular test carried out on 100 new 49 x 17 aircraft tires, the author found that 3% of the tires contained separations over one inch in diameter at the turn-up edge due to pieces of poly. The fact that at least one of these could have lead to a critical failure within its normal life expectancy is without a doubt.

But now let us come back to the basic point. Given the fact that separations do exist in aircraft tires, how many exist, and when they do exist in a given construction, how fast do they propagate? When and under what circumstances do they lead to failure? What is the proper time to take tires off of a given system so as to get the maximum usefulness out of a tire purchased?

To get a preliminary feeling for the answers to these questions, (a final answer is not yet possible), six descriptions follow of random samplings from a mixture of R levels taken from a few thousand aircraft tire tests. Let us choose first a random sampling (Sample #1) of 100 - 20 x 4.4 tires. About 9% of this sample were separated. Based on our data to this date, we would consider about 6% of that 9% to be moderately critical, implying that there is a given probability of failure within the life span of the carcass or more specifically, that there is a high probability that the tire would not pass a qualification test. Within this 6%, about 3% of the tires contained one-quarter inch or larger separations combined with poor structural uniformity such as nonuniform cord tension or fatigue. On the other hand as a comparison to this sample, the author has observed a group of 300, 20 x 4.4's in which not one single separation was found. Wi n'n this group, probably not more than one to th.. .would fail the basic qualification test for the 20 x 4.4. However, we realize that the indoor qualification wheel test is undoubtedly more severe than the real world situation. In actual usage, all 300 of these tires would probably have lived out their full carcass lives over two or three R levels without mishap.

A more typical case (Sample #2) for 20 x 4.4's would be to find three to five seriously defective tires among a sample of 500, or about 1%. The percentage of critically defective tires in a given sample lot will vary significantly when testing tires manufactured by different companies. In other words, a much more significant variation in data appears when comparing different original tire manufacturers as opposed to observing different retreaders. The quality of tires also vary as a function of the date of manufacturers.

Next note a more typical random sample (Sample #3) in 30 x 8.8 tires. In this sample, of the one hundred tires chosen, only two were separated. And of those two tires, only one had a very high probability of premature failure since critical nonuniformity surrounded the separation.

Our next sample (Sample #4) is of 100 tires, size 40 x 14 - Manufacturer A. In this case, 41% of the tires were seriously defective and rejected, based on a rejection criteria for separations of 1/2" ± 1/4" or larger where the variation, ± 1/4", is a function of the overall strength of the carcass or structural uniformity. Most of the separations in the 41% were serious shoulder and/or splice separations. Less concern was given to the separations existing in the center or crown region of the tire as opposed to separations in the more critical shoulder regions. The ± 1/4" variation was used to single out

strong and weak tire carcasses. In other words, a separation as large as three quarters of an inch inch would be allowed in a tire with a strong carcass, whereas a separation only as large as one quarter of an inch would be allowed in a carcass which was weak and fatigued. We should also note that a few tires in the 41% rejection criteria were rejected solely on the basis of extremely weak and loose carcasses; that is, carcasses containing no separations. We tested a number of these rejects (from the moderately-high-probability-of-failure types to the very-high-probability-of-failure types) on the indoor test wheel and they all, without exception, failed prematurely.

The questions, "What do you mean by critical separation?", or "How does one establish an acceptance-rejection criteria?", need to be answered. Acceptance-rejection criteria must be established on a very substantial data base; 100 tires is not substantial enough. After testing over 1000, 40 x 14's, we began to establish a good degree of confidence in terms of an acceptance-rejection criteria, which is 1/2" ± 1/4" where the variation of ± 1/4" as mentioned above is a function of the carcass strength. Now let us look at a sample of 100, 49 x 17's, which is Sample #5. Here, 11 tires were rejected. Although in this case we have not looked at enough tires to clearly establish an acceptance-rejection criteria, our general feeling is that separations up to one inch in diameter in the crown area are acceptable for an additional R level as long as the carcass is strong. However, only separations smaller than one-quarter inch would be tolerated in the turn-up area or shoulder areas.

Now let us digress momentarily to point out that the seriousness of a separation is established while observing, as a result of repeated tests through many R levels, the propagation rate of the separation as a function of the number of landings. In addition, the propagation of separation as a function of the number of taxi-take off cycles has been studied (the author has studied repeated tests on approximately 27 tires) on indoor test wheels. There is a desperate need for more indoor test data, since we have only scratched the surface of this immensely fruitful area of research. Furthermore, one establishes a very good feeling for how fast a separation propagates by observing from R level to R level how fast the tire is deteriorating both from the point of view of the structural uniformity and the structural integrity (the size of the separation as a function of the number of landings). By observing the increase in size of very small separations from R level to R level, one obtains a feeling or judgment as to how many landings a tire will go through before the separation reaches a size where the tire will fail. We have

observed both real world failures (failures on actual aircraft) in addition to failure cases which were simulated on indoor test wheels.

Next let us look at a larger sample (Sample #6) of 40 x 14's - Manufacturer B. In this distribution of 1000 tires, there is a total mixture between R-0's, R-1's, R-2's, henceforth, on up through the R-5 level. The basic distribution contained more R-2 levels than any other specific level. The rejection over the first 1000 tires based on our data base was 21.5%; however, these rejections were based on both separations and loose splice detail combined with overall cord looseness and tire fatigue. In other words, about 15% ± 3% of the total would be considered to be critical. And, in this case, we would define critical as meaning those tires which would have an above average probability of failing had the tire not been rejected prior to the next R level. A special note should be made that many of the tires we observed which contained critical separations were removed from service prior to failure due to cuts, skid burns, etc. Had the tire in the sample been more resistant to cuts, for example, the airline would have experienced even more than the typical one failure per month which was their situation. A brief note should be made that many of the serious shoulder separations which were in structural weak areas were not revealed by air needle injection.

A few additional comments might be in order with regard to the distribution of 100 new 49 x 17 tires. One percent, or one tire, contained a very critical shoulder separation which could have lead to a serious problem. Three percent, or three of the tires, contained crown separations with an average size of two inches in diameter. Separations of this size could lead to a problem previous to the next R levels. Five percent, or five tires, contained separations at the turn-up, flipper strip edge, and in the apex strip region above the beads. Another one percent, or one tire, exhibited very poor cord adhesion characteristics. Upon examining the eleven tires of special concern, we might note that tire #1 contained a crown separation over 1/2 inch. Tire #2 contained a 1" crown separation. Tire #3 contained a separation in excess of 1" at the turn-up. Tire #4 contained a separation in excess of 1" at the turn-up. Tire #5 exhibited cord socketing to an extent which could lead to a serious problem. Tire #6 had only a very small separation which would undoubtedly not lead to a problem. Tire #7 contained a 2" separation at the bead apex. Tire #8 contained a 1" separation at the bead apex. Tire #9 contained a separation in excess of 3" in the shoulder. This tire obviously had a high probability of premature failure - and soon. Tire #10 contained

a 3" separation at the turn-up. Tire #11 had weak tread adhesion in general. The remaining 89 tires had a very low probability of failure and were excellent candidates for further retreading. It is important to note that all of these 100, 49 x 17's were new R-0's. Throughout the R-0 level, we would consider only one of these above eleven to have a very high probability of failure prior of the next R level; this tire being tire #9, -- the one with the 3" separation in the shoulder. Had any of the above eleven tires been overloaded and underflated at the same time at least five of the eleven would have had a high probability of premature failure.

Considering R levels beyond R-1, there now is a probability of failure which begins to become noteworthy even under normal loading conditions in tires #10, 3, 7; the tire containing the 3" separation at the turn-up, the tire containing the 1" separation at the turn-up, and the tire containing the 2" separation at the apex.

We should again ask ourselves the question, "What constitutes a critical defect?", that is, a defect which has a very high probability of failure prior to the next R level. And, how does one go about getting data which relates to defect criticality?

Allow me to digress momentarily to say that the beauty of truck tire testing lies in the fact that the data is so much easier to obtain. One simply sorts out defective truck tires from good truck tires, selects several hundred, and then mounts them on trucks in fleets with defective tires running along side good strong tires to minimize any possible danger of a serious situation occurring. Over ensuing months, and observations of many tire failures, it is easy to establish a clear cut criticality, or acceptance-rejection criteria. Such data can certainly be obtained in a one to two year period.

But, what can one do to establish criticality in the case of aircraft tires? First, one tests a very large number of tires and separates out those which have a lack of structural integrity (separations) and/or lack of structural uniformity (poor construction geometry, loose cord tension, fatigue, etc.). With aircraft tires, we cannot submit them to actual stress experiences as in the case of truck tires. Instead, we must sort out those tires having defects which appear to be of a critical nature and put those tires on an indoor test wheel to run them out to failure. After having done so, we must establish the basic rate of propagation as a function of the number of cycles or landings. The obvious problem lies in the fact that real world failure data is nearly impossible to obtain and the gathering of data on

an indoor wheel is slow and expensive. One researcher can direct a study on a thousand truck tires in the same period of time it takes to carry out failure analysis on 50 aircraft tires. Further work in this area is critically needed.

Before proceeding to a discussion of results on indoor test wheels to establish defect size criticality, it might be interesting to point out that in the case of a 40 x 14 tire, we made a mistake in the early stages of our testing and allowed a tire which contained a 2" separation to get placed into the "tires accepted" category as opposed to the "tires rejected" category. At that time, we were using an acceptance-rejection criteria of 1/2 inch. That tire, containing a 2" separation, was accidently mounted on an aircraft *and it failed on the fifth taxi-take off.* We were very fortunate in that the failure did not lead to a serious situation as it could have. As a result of this experience, we believe that a 2" separation would obviously go to failure very quickly.

But what about the case of the 1/4", or 1/2", or 3/4" separations? How soon would they fail? Our next step was to take these types of separations to the indoor test wheel and to observe their propagation as a function of the number of cycles. (However, it is not always necessary to go to the indoor wheel.) As our first example of the indoor test wheel, we will look at a 40 x 14 - 21 tire and observe the increase in the separation diameter propagation as a function of the number of taxi-take off cycles. In this first case, we observed in the original carcass a 7/8" diameter separation. The tire was then mounted on the indoor wheel and after a brief warm-up period, the tire was cycled through five taxi-take off cycles. The tire was then taken off the test wheel, dismounted, and then reholographed. At this time, we observed that the 7/8" diameter separation had grown to 1-1/2" in diameter. The process was repeated for another five taxi-take off cycles and the 1-1/2" diameter separation had now grown up to 6" in diameter. Other separations had grown in diameter which were close to the original 7/8" diameter separation. These separations, as they had grown, had also joined up into the above mentioned 6" diameter separation. Again, a 1/8" diameter separation in this same carcass, which was originally close to the previously mentioned 7/8" diameter separation, grew after five cycles to a 3/4" separation. Then after having had the process repeated, grew from a 3/4" separation in an additional five taxi-take off cycles up into the 6" separation mentioned earlier. At the same time, an original 1/2" diameter separation, which was at a further distance from the original two separations mentioned, after five taxi-take off cycles had grown to 1-1/4 inches. Then after another five taxi-take off cycles had reached out and joined into the above mentioned

6" separation. In other words, the original 7/8" diameter, 1/8" diameter, and 1/2" diameter separations all grew significantly and finally ended up after ten taxi-take off cycles in a single 6" diameter separation which then, in turn, went to failure after six additional cycles.

Let us give an additional example in a 40 x 14 - 21 aircraft tire. In this tire once again, there was a considerable lack of structural uniformity throughout. In this case, a 1/2" diameter separation in the original measurement propagated to a 1-1/2" diameter separation after five cycles which, in turn, propagated to a 5.5" diameter separation after yet another five cycles. Another original 1/4" separation propagated to 1/2" in diameter after five cycles which, in turn, propagated to 4" after five more cycles. So, therefore, we note that separations in the 1/4" to 1/2" category propagate quite quickly, particularly when they are in a tire which is structurally weak and/or the separation is in a shoulder region as the above cases were.

Next, allow me to give four examples of propagation of separation in aircraft tires - size 26 x 6.6. Due to the shortness of this paper, our examples of this propagation will be brief. In the first, on 26 x 6.6's, a 1/4" separation at 127° in the crown area of the tire propagated to a 1/2" separation after five cycles which, in turn, propagated to 5/8" after five more cycles, which in turn propagated into a 5" separation after yet another five cycles. An original 1/4" separation at 143° propagated to 1/2" after five cycles, and then propagated to 3/4" after yet five more cycles, and finally propagated into the 5" separation mentioned above after five more cycles. A third separation at 153° in the crown which was 3/4" in diameter propagated to 7/8" in five cycles, which in turn propagated to 1" in five additional cycles, which in turn joined into the above mentioned 5" separation. The 5" separation then, in turn, failed after four more cycles. From the above, we note that separations ranging from 1/4" to 3/4" propagate quite rapidly as a function of the number of cycles. Moreover, these individual separations have propagated this quickly as a result of the fact that they were clustered quite close together. Had these separations been further apart, or had they existed singularly, they would not have propagated as fast.

Next let us look at an example of a 1" separation in a 26 x 6.6 tire. This separation propagated after five cycles into a 2" separation which, in turn, after five more cycles propagated into a 4" separation which, in turn, propagated to failure at the beginning of the sixth cycle.

Another description is of a 26 x 6.6 tire which had a very weak carcass. This tire originally had a separation, 3/8" in diameter, which propagated to a 3" separation in five cycles which, in

turn, propagated into a 12" separation in five additional cycles which, in turn, failed before the next cycle was completed.

Next allow me to provide a brief example of a tire which showed extreme nonuniformity in weakness throughout the carcass, but contained no separation initially. It exhibited the fact that a tire which had extreme amounts of fatigue and structural nonuniformity would develop separations very quickly. In this case, after five cycles a 1/4" separation evolved at a specific point. This 1/4" separation in turn propagated to a 2-1/2" separation within five additional taxi-take off cycles which, in turn, propagated to a 20" separation after five additional taxi-take offs.

This type of data could be given in great detail for a large number of examples, but it represents the typical type of information that one obtains on an indoor test wheel. Needless to say, high quality "control tires," observed holographically, ran beside these without mishap. (In a number of cases, as an aside comment, we have predicted the success or failure of tires being sent through conventional qualification tests required by the Navy.) In summary, we can say that when separations exist in a 26 x 6.6 aircraft tire in the size category of 1/2" ± 1/4", they will propagate to failure in a surprisingly short period of time especially if the carcass has poor structural uniformity (low adhesion levels being one of the more critical situations in the 26 x 6.6's). On the other hand, if a separation exists in the 1/2" ± 1/4" category, it will go through a significantly larger number of cycles (25 to 50) before it goes to failure if the carcass possesses a high degree of structural uniformity. Rather than give a large amount of data in this short paper, the author is presently preparing a publication which provides more detailed information on separation propagation as a function of the number of taxi-take off cycles on indoor test wheels.

Before proceeding, mention should be made about the percentage of rejections as a function of a given R level for commercial aircraft tires. We have found throughout our statistics that roughly speaking the same percentage of rejections plus or minus 10% take place at each R level in large distributions of 40 x 14 - 21 aircraft tires. This data would suggest that separations are appearing at each R level at about the same rate. Separations continue to appear as the cords loosen up and general fatigue sets in. Much of the data which we have observed to date in 40 x 14's would suggest that one would be wise not to make the decision to reject a tire based on a given R level. It would appear to be a much wiser criteria to decide on the life of a tire based on the number of cycles or landings it goes through rather than

the number of R levels. This is the data which must be obtained in the future. We strongly feel at this time that once an understanding is obtained of the degradation of a carcass as a function of the number of landings, decisions should be made wherein a tire is allowed to stay on an aircraft as a function of the number of landings and not as a function of the number of R levels. It is conceivable that a tire with a R level of, for example 5 or 6, could have significantly less landings on it than another tire which is only an R-2 or R-3. This could partially explain the reason why we sometimes see less fatigue in an R-5 or R-6 than we might in an R-3 or R-4.

Next we note in terms of the failure mechanism characteristics of a given tire construction that the small separations propagate very slowly if they are in a very strong tire and that these separations will propagate out through a number of R levels before the background carcass begins to weaken, to loosen up, and then go to terminal failure over a fairly short number of cycles. Now let us compare the above notation very briefly to truck tires whose separation propagation rates are well behaved. If we were to look at separation size as a function of mileage and draw a graph for truck tire data, we would notice that it would fall very nicely along a given line. In general, the relationship between separation size and mileage is a linear function with the variation in slope of that line being determined by the overall strength of the tire. In the case of truck tires, we then have a band of linear traces whose milder slope represents tires which are quite strong. Those linear traces with a stronger or higher slope represent tires which are weaker.

When measuring aircraft tires, we think in terms of the number of taxi-take off cycles versus separation size. Here, we notice that a small separation will typically propagate in a strong tire slowly wherein the curve along which it travels (that is the separation diameter as a function of cycles) will look very much like the truck tire case. After many cycles, and after the carcass has begun to fatigue and loosen up, there will be an increase in separation size as a function of cycles which will increase exponentially to the terminal failure point. In a tire which has a very weak carcass, we will note that the separation size will increase exponentially as a function of the number of cycles in very early stages whereas, as mentioned above, the separation size as a function of a number of cycles will increase linearly with a very mild slope for a long period of time and will then rise exponentially in a strong tire. As mentioned earlier, the cardinal difference between truck tires and aircraft tires is the following point. Almost without exception, all separations or areas with a high probability of separation will be observed in the original

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carcass at the time the tire is new. Even after the tire has been retreaded, new separations are unlikely to appear in a radial truck tire unless they are the result of mistakes the retreader has made. New separations which are specifically a function of the carcasses themselves do not appear at these later stages. Conversely, in the case of aircraft tires, the separations which are observed at various periods during the life of a given aircraft tire carcass seldom appear when the tire is new or straight out of the mold. As a matter of fact, on the average, rarely does one see in new aircraft tires more than 1% or 2% which are separated. On the other hand, after a number of cycles, perhaps 1000 landings, which may be at a R-5 level, one might note a number of separations in a given tire carcass which did not appear either at the early stage of the tire's life, or in the previous R level. In other words, separations continue to form and propagate at a variety of stages throughout an aircraft tire's life (throughout each of its R level stages). It is not uncommon to see no separation in a R-0 level of a given tire, or its R-1 level, or its R-2 level and on up to some R-n level whereupon separations will appear over a very short period of time and with great profusion. When establishing acceptance-rejection criteria, this would lead one to the conclusion that aircraft tires must:

(A) be studied to determine the type and location of separation which will form and the average rate of propagation of these separations. The rate of propagation is by far the most significant parameter for a given tire.

(B) be studied to determine the type of failure mechanism which a given construction experiences. Furthermore, it is evident that the tire must be tested intermittently after a given number of landings. In the case of 40 x 14 - 21, the number of landings associated with a given R level for example from R-1 to R-2 in a typical DC-9 operation, turns out to be just about the ideal spacing for the frequency of testing.

(C) be studied by holography before and after each R level to determine the optimum number of landings for a given size, construction, and manufacturer. In the future, this test time can be established as a function of the number of landings a tire experiences, provided that the inflation pressure has been maintained throughout the period under consideration. Note: underflation will significantly increase the propagation rate of separations. If a tire reaches an established number of landings, it should be retested prior to further use.

The following information is the result of our first commercial carrier studies which were carried out over the past two years. This carrier was experiencing approximately one tire failure per month over a one year period with an average cost per failure (amortized over the year) ranging between $20,000 and $25,000, due to structural damage to the aircraft and rubber ingestions in the engines. Over a relatively short period of time, all the tires in service of a given type were holographically tested and all tires with separations greater than one-half inch in diameter were rejected. Since the tires with separation over one-half inch were taken out of the systems no tire failures were experienced over the following two years. It is important to note that this type of testing will not eliminate all tire failures, but it can significantly reduce the incidence of failure which has been dramatically proven in more than one airline. It is interesting to note that the original rejection rate in the above case was slightly over 20%, whereas after culling out the tires containing separations over one-half inch in diameter, the rejection rate fell to around 12%. Further analysis has revealed that larger separations can be tolerated in the crown area which puts the rejection rate under 10%.

Now to summarize. The basic objective of this talk has been to comment upon the meaning of separations in aircraft tires. You can look at a large distribution of tires and discover, as Mr. Shaver, the Engineering Vice President of Air Treads, Inc., has pointed out so aptly and carefully, "large distributions of tires have very low incidences of separation - at times as low as 1%." Then we will note other case histories, where the percentages can get significantly over 10%. Our basic objective at this time is to understand more thoroughly the background strength criteria in aircraft tires and to establish an acceptance-rejection criteria based on a fairly large data base. In general, we would like to test 1000 tires in a distribution and then cull out those tires which have separations. The tires pulled out must be evaluated to determine separate propagation rates as a function of structural uniformity. Acceptance-rejection rates should then be established and then routine testing of the tires should be carried out at each R level where the R level does not exceed a given number of landings for a given tire size and construction. It has been said, "Well, you see most separations in retreaded tires; you don't see many of them in new tires." This is a misleading point. Although separation does not exhibit itself until an advanced stage in a tire's life, the original construction and the care with which the original tire is built has a significant impact on the amount of separations which will appear in the tire's later life. Needless to say, we find that retreading practices are not often the cause of separation in aircraft tires.

It is only going to be with the greatest of effort and patience that the separation propagation rates

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and basic failure mechanisms are understood whereupon realistic acceptance-rejection requirements can be placed on a given tire despite the fact that relatively few tires contain separation. Although all tires experience fatigue as a function of usage which will, in turn, eventually lead to separation, the general performance of the typical aircraft tire far exceeds that of most typical engineering systems. Aircraft tires perform an extraordinary job in terms of the requirements that are placed on them and the abuse given to them. With some modest effort, great improvements can be made at relatively low costs resulting in an example of one of the most impressive engineering systems of our day - namely the typical run-of-the-mill aircraft tire.

QUESTIONS - deleted at author's request, Editor

ARMY PROGRAM IN NDT OF TIRES

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The Army program in NDT of Tires is directed for the most part toward retreaded military truck tires because the Army retreads over one-half million tires each year under a mandated materials conservation effort. While many tires are retreaded at Army facilities, a large percentage go to local procurement. Thus, the Army interest in equipment development is first directed to the very start of the retread cycle: determining carcass integrity to sort the carcasses before they reach the buffers of either Army or civilian facilities.

The second major Army interest is generated by the nature of tire usage and procurement that is probably peculiar only to the vast fleet of the Army. Because of the large number of mounted and unmounted tires in the fleet and in supply channels, and because so many vehicles receive minimal use over extended periods, there is considerable aging and general deterioration of the tires. So that we will have a true picture of our operational readiness, a continuing study is being made to learn how much of this degradation can be appraised and how much is significant to tire life expectancy. Elaboration on these two areas will be made in the four papers that will follow and which will report the in-house and contractual efforts that are currently under way in support of the Army's program in NDT of tires.

NONDESTRUCTIVE MEASUREMENT OF CASING QUALITY

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INTRODUCTION

The large volume of tires used on DoD vehicles
necessitates an extensive retread program within
DoD (and especially within the Army). A simple,
low cost, reliable method of determining the
integrity of a tire casing prior to the retreading
operation is very desirable. The Product Assur-
ance Directorate (AMSTA-Q) and the Maintenance
Director are (AMSTA-M) of the Army Tank Auto-
motive Command are co-sponsoring a program to
develop such a method. There are several non-
destructive inspection methods presently being
applied to tires: X-radiography, infrared, holog-
raphy, and ultrasonics. All of these methods
are capable of detecting defects in tires. How-
ever, on analysis, ultrasonics seems to best ful-
fill the Army requirements of low cost and simple
application.

Figure 1. Ultrasonic tire inspection system.

There are a number of ultrasonic techniques use-
able for this application. Both thru transmission
and pulse-echo were evaluated. The inherent
mechanical simplicity of a single transducer
pulse-echo system, its depth discrimination capa-
bility allowing a casing evaluation independent
of tread presence or thickness, and its ability
to provide on-vehicle, wheel-mounted, tire in-
spection made pulse-echo our choice as an inspec-
tion tool.

INSPECTION SYSTEM

A retread - production - oriented, ultrasonic
pulse-echo inspection system was developed for
the Army to check the method's practicality. It
incorporates the transducer positioning require-
ments to inspect a range of tire sizes (7:00 x
16, 9:00 x 16, 9:00 x 20, and 11:00 x 20). The
system has power tire mounting and rotation fea-
tures, and incorporates a modified commercial
ultrasonic inspection unit.

Figure 2. Transducers and holding fixture.

The inspection system developed is shown in Figure
1. Briefly, it contains an immersion tank nece-
ssary to couple the high frequency ultrasonic
energy into the tire, the transducers and fixtur-
ing required to inspect the tire sizes mentioned,
and mechanical equipment to simplify the handling.
Figure 2 shows three transducers mounted to a
fixture which permits setting of transducer angle
for the various tire sizes to be inspected. We
inspect the mid-line and shoulder areas of each
tire. The tire handling equipment is shown in

Figure 3. It consists of a modified Branick Tire
Spreader, a pneumatic lift table, and a rotary
bearing to allow the tire to be placed in the
tank.

The tire handling procedure is straightforward
and is made with production inspection in mind:
mounted onto the spreader, it is lifted above the
water tank walls, rotated 90 degrees, and lowered
into the water tank. The tire is then ready for
ultrasonic inspection. The procedure is reversed
to remove the tire from the system.

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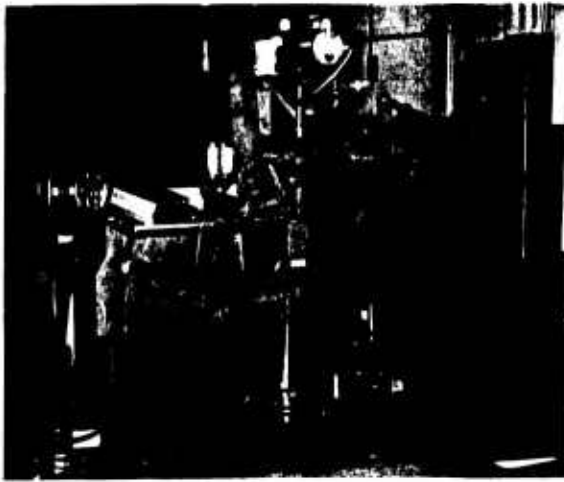
Figure 3. Tire handling equipment.

The ultrasonic instrument has an automatic audible alarm system which tells an operator of the presence of a defect.

Figure 4 is a recording of the instrument's oscilloscope trace. The recording in Figure 4a shows the ultrasonic pattern from a tire which does not contain a defect. The photograph in 4b shows the ultrasonic pattern which has a defect. Figure 5 is a photograph of this defect which was found by automatic alarm inspection. The defect is a break about 3/8" deep. It extends through the outer breaker belts and into the first outer ply layer. This type of defect would not be found during buffing. An example of the other type of defect defected ultrasonically and confirmed by buffing is shown in Figure 6. It is a typical tread/ply separation in the shoulder of the tire.

a. Tire which does not contain a defect.
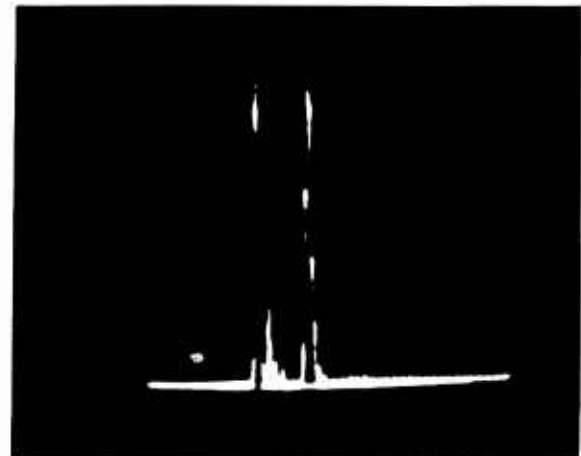
b. Tire with a defect.

Figure 4. Ultrasonic tire defect detection.

TESTING

In order to determine the adequacy of the system developed, it was necessary to develop statistical data on the type, number, and location of detectable flaws in tires. A tire testing program was, therefore, conducted. Four hundred-fifty tires were inspected.

DISCUSSION

Figure 7 summarizes the results of the inspection. Comparison of ultrasonic test results with optical examination and physical test data confirmed that six percent of the tires had what can be described as localized defects (nail holes, separations, breaks, etc.). Forty-six percent had what can be described as circumferential defect indications (defined as a general deteriorated condition around most or all of the circumference of the tire).

Sixteen percent of the localized defects (1% of all tires tested) consisted of inclusions or breaks. Eighty-four percent (5% of all tires tested) consisted of either cord or ply separations. Sixteen tires which presented localized ultrasonic defect indications were sectioned and examined. Visual confirmation was obtained for each of the ultrasonic indications.

Forty-six percent of the tires inspected had circumferential defect indications. Fifty percent of the circumferential defects (24% of all tires tested) were found to be associated with low tread bond, 22% (10% of all tires) were cord separations or outer ply deterioration, and 28% (12% of all tires) were loose cords. Twenty tires exhibiting circumferential ultrasonic inspection indications were sectioned, visually examined, and subjected to peel test.

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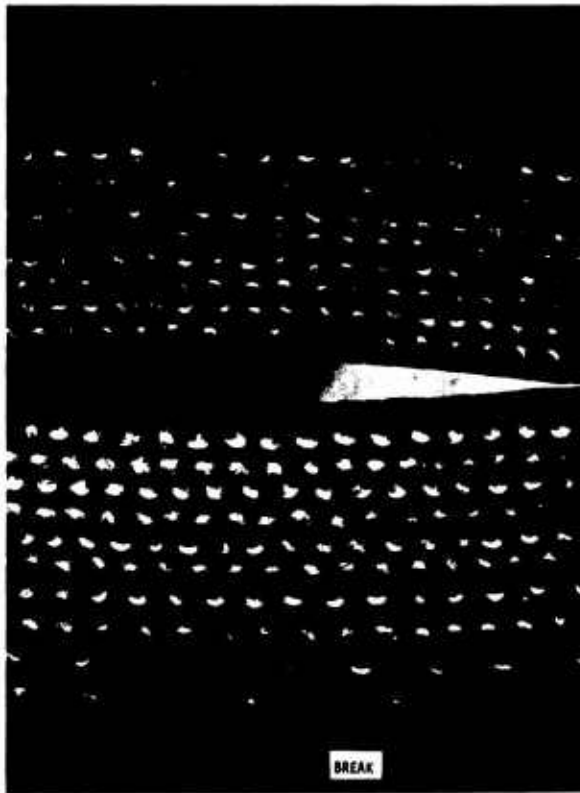
Figure 5. Cross section of break detected.

SEPARATION

Figure 6. Tread/ply separation detected.

INSPECTION	INDICATION OCCURRENCE	DEFECT	DEFECT OCCURENCE
LOCALIZED	< 6%	INCLUSION	< 1%
		BREAK	
		CORD SEPARATION	5%
		PLY SEPARATION	
CIRCUMFERENTIAL	46%	LOW TREAD BOND	24%
		CORD SEPARATION	10%
		OUTER PLY DETERIORATION	
		LOOSE CORD	12%

Figure 7. Inspection results.

In summary, correlation of mechanical and visual test results with ultrasonic inspection data (from Military tires) had demonstrated three significant items:

   (1) Localized defect occurrence is small;
   (2) circumferential defects are significant in number; and
   (3) ultrasonics can find both.

The first two, together, indicate that the prime Army emphasis heretofore placed upon the detection of localized tire defects may be misplaced. As a result, our current research is directed primarily towards evaluation of casing quality based upon general tire state of degradation.

DEGRADATION MEASUREMENT

An analysis of the ultrasonic signals, microscopic observations, and peel test properties indicated that a relationship exists between reflected circumferential ultrasonic signals from tire plies and casing degradation.

Visual observation has shown that certain ultrasonic reflection signals are associated with strong interply adhesion and tight cords; other signals are correlated with loosening of the

rubber-cord matrix; still other signals indicate total matrix degradation. Figure 8 shows cut tire sections having a) loose cords and b) matrix separation. These conditions can be ultrasonically segregated from each other and from a tight matrix of a new or little used tire.

It was assumed, that as a tire casing goes through its useful life, it "degrades" (i.e., the cord-rubber matrix transforms from tight to loose to separated). Thus, an instrument which could monitor such progression could predict remaining useful life of a tire casing.

To evaluate this theory, tires being road tested at the Army Yuma Proving Grounds were monitored. Figure 9 shows that actual mileage on tires were monitored by this ultrasonic technique. The curve represents an average of many tires while the vertical drop at 6000 miles represents either damage caused during retreading or the uncertainty about the retread level of the tires.

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Loose Cords

Matrix Separation
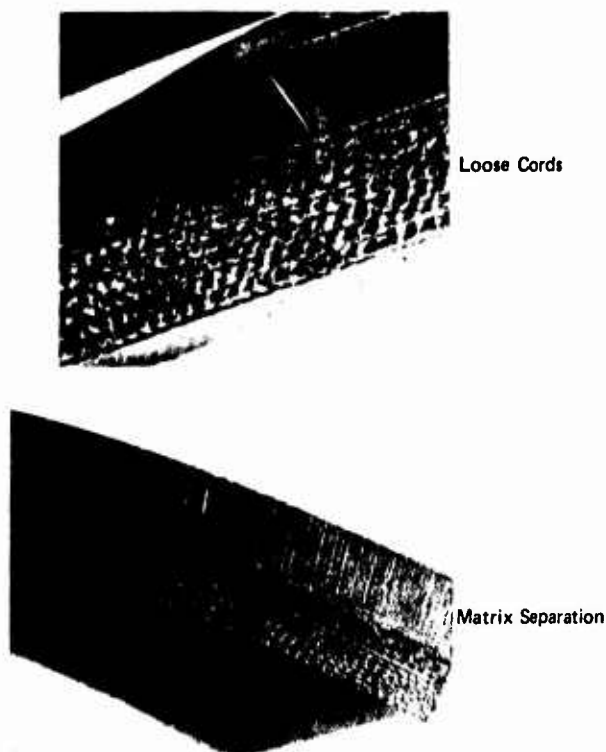
Figure 8. Tire degradation stages detected ultrasonically.

ROAD MILES (THOUSANDS)
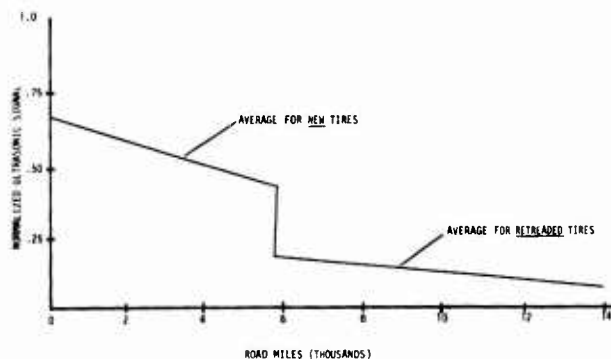
Figure 9. Preliminary road test data.

Figure 10 shows an actual on-vehicle tire degradation measurement being performed at Yuma. As can be seen, it is performed with a portable instrument using hand contact of the sensor. The inspection time per tire is about one minute. Initial results with the technique have been

favorable enough that GARD is currently under contract to the Army to develop quantitative data for incorporation into maintenance procedures to establish accept/reject criteria for retreadability of tire casings based upon retread and new tire costs.

For those who may be interested, we have a demonstration of the technique set up upstairs. We are anxious to explore the commercial possibilities of this equipment and we will welcome your comments and suggestions. We have no reason not to believe that commercial truck and passenger tires behave in the same manner as military tires. In fact, we have limited data on passenger and truck tires which tend to confirm that they do behave similarly. We intend to pursue this area further during the coming year.

Figure 10. On-vehicle tire degradation measurement.

QUESTIONS AND ANSWERS

Q: How much does a commercial unit cost?
A: We're currently trying to figure out how many we can sell, but I think the range we're talking about is $5000, maybe $6000, depending on how many we think we can sell. I think the important thing to stress here is the reason this unit might be less expensive than most of the other units. We do not feel a need to go to the mechanical handling that you need when you look at ply separations. Frankly, the electronics and so on may be roughly comparable in all the different techniques.

ULTRASONICS VERSUS ROAD TESTING

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INTRODUCTION

From the period of July 1974 to May 1975 the Product Assurance Directorate of the U.S. Army Tank-Automotive Command (TACOM), Warren, Michigan, conducted tests to compare the wear characteristics of new and retread tires.

Three tire sizes were used for the test. These were the 700 x 16, 900 x 20, and 1100 x 20 non-directional cross-country (NDCC) bias ply tires. These three sizes have the highest density in the Army system.

The test was conducted at Yuma Proving Grounds, Yuma, Arizona. This site was chosen because of its severe climate and terrain, probably the worst conditions to which a tire can be subjected.

In conjunction with the wear test, the tires were evaluated using ultrasonic inspection techniques developed by TACOM's Product Assurance and Maintenance Directorates. The objective of the ultrasonic evaluation was to provide statistical data on the condition of the retread bond line and tire cords and to relate this data to tire performance.

SYSTEM DESCRIPTION

The ultrasonic test equipment, used to nondestructively inspect the tires in the test at Yuma Proving Grounds, consisted primarily of an ultrasonic transducer, used to transmit and receive ultrasonic pulses and a cathode ray tube scope, used to display the reflected sound waves.

The ultrasonic inspection technique employed is the pulse-echo method. Using this method, an ultrasonic beam is transmitted into the tire at the ply layers, the beam is reflected and the echo is received by the same transducer used to transmit the beam. A schematic of the pulse-echo process is shown in Figure 1.

The various tire interfaces that produce signals on the scope and their corresponding background signals are shown in Figure 2. Figure 3 illustrates the various scope displays that can be encountered while inspecting tires using ultrasonics. The normal condition implies that the tire is basically sound, with no ply separation

ULTRASONIC TRANSDUCER

TRANSMITTED PULSE

REFLECTED PULSE
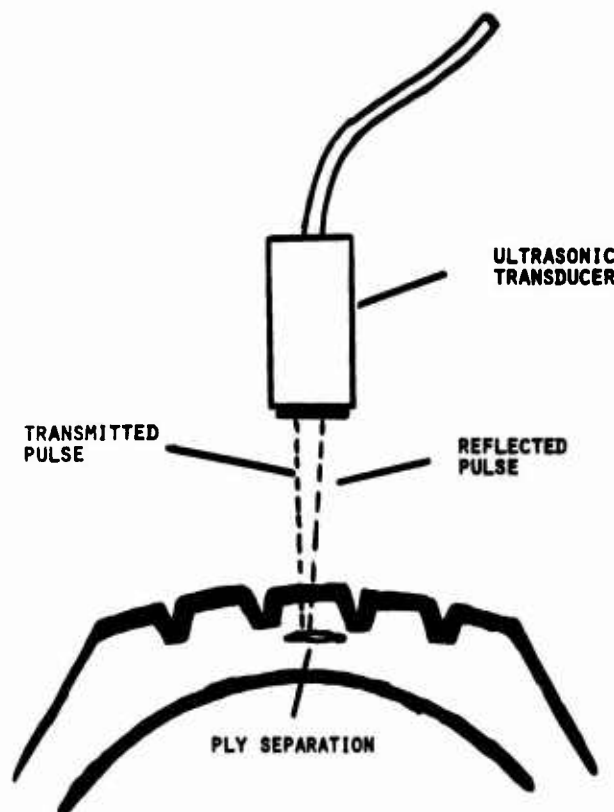
PLY SEPARATION

Figure 1. Pulse echo method of ultrasonic tire inspection.

or degradation. A low signal indicates loosening or unraveling of individual cords. The high signal (spike) indicates separation of the cords from the surrounding rubber. These various conditions are illustrated in Table 1.

INSPECTION PROCEDURE

For the Yuma test, a contact inspection method was employed. In this method, the transducer is in direct contact with the tire coupled through a thin film of oil and water.

Each tire was inspected along the centerline for approximately fifteen inches around the circumference of the tire and approximately four readings were taken and averaged. The following data was recorded for each tire: Tire size, cord material, background level, bond-line level, date of
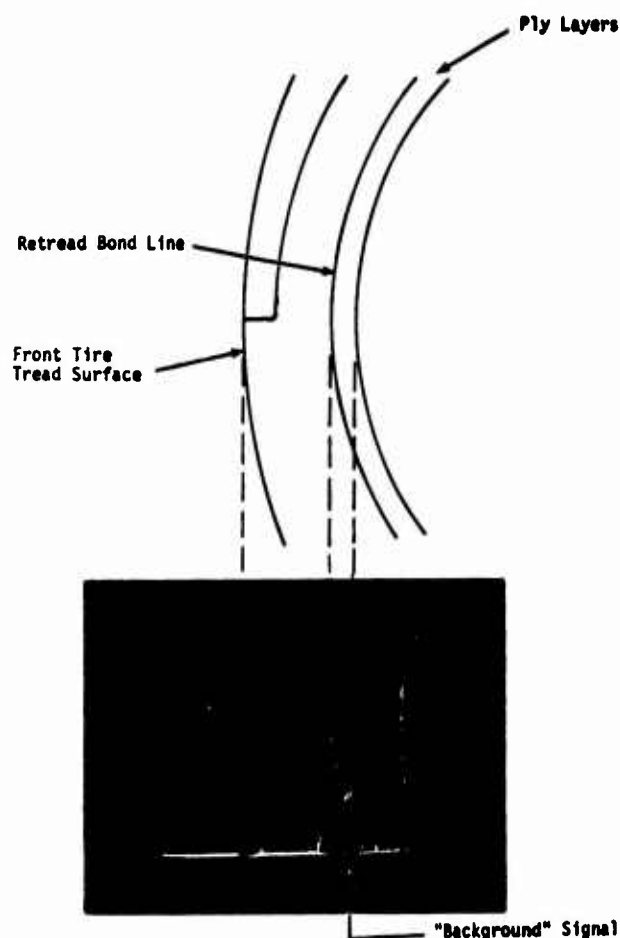
Figure 2. Schematic of tire interfaces.

"Normal" condition

"Low" condition
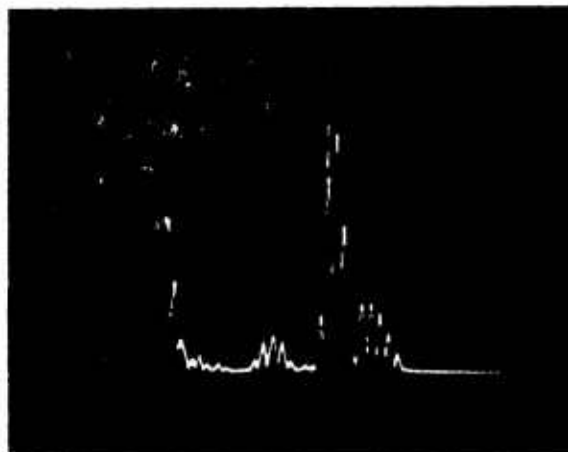
"High" condition

Figure 3. Typical ultrasonic ply background A-scan presentation.

manufacture, original manufacturer, tire test code number, new or retreaded tire, position on the vehicle, test miles, and cause of test termination.

INSPECTION RESULTS

The following analysis of the ultrasonic test data is centered around the 1100 x 20 retread bias-ply tires. This is due to the fact that more pertinent data is available for this size than for the 900 x 20 or the 700 x 16, because the ultrasonic test equipment was not available at the beginning of their testing, thus readings were taken only upon test completion for the latter two sizes. However, examination of the after test readings for all three sizes indicates a high degree of correlation, which would indicate that the results obtained in the analysis of the 1100 x 20 data is representative for the 700 x 16 and 900 x 20 size tires. Figure 4 shows the high degree of similarity between after test readings for the three sizes of tires.

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Table 1. CASING DEGRADATION INDICATION

CORD/RUBBER MODEL			
CORD/RUBBER CONDITION	NORMAL	LOOSE CORD	CORD SEPARATION
ULTRASONIC SIGNAL (IDEALIZED)			
ULTRASONIC CLASSIFICATION	NORMAL	LOW	HI
PEEL STRENGTH	100%	90%	65%

The first step in the analysis was to relate the ultrasonic background readings to the total test population of 1100 x 20 retread tires. Figure 5 shows the population density of the test tires with regard to their ultrasonic background readings. A majority of the tires were in the 10 to 20% range before the test started, however, the significant indicator of degradation lies in the fact that when the test was completed all 40 to 50% readings had disappeared.

A life cycle curve or "map" for the 1100 x 20 tires is shown in Figure 6. This map illustrates the degradation with occurs in tires as they run to failure. The points were obtained by plotting average background readings versus average mileage. Segment 1-2 represents the degradation which occurs in new tires as they are run to failure or wearout. Segment 3-4 represents the degradation occurring in
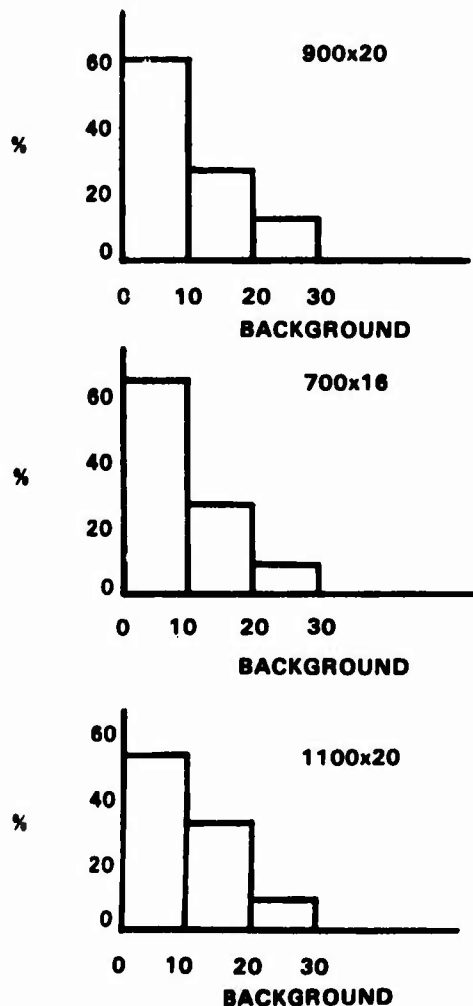
Figure 4. Percentage of total population versus ultrasonic background reading after test.
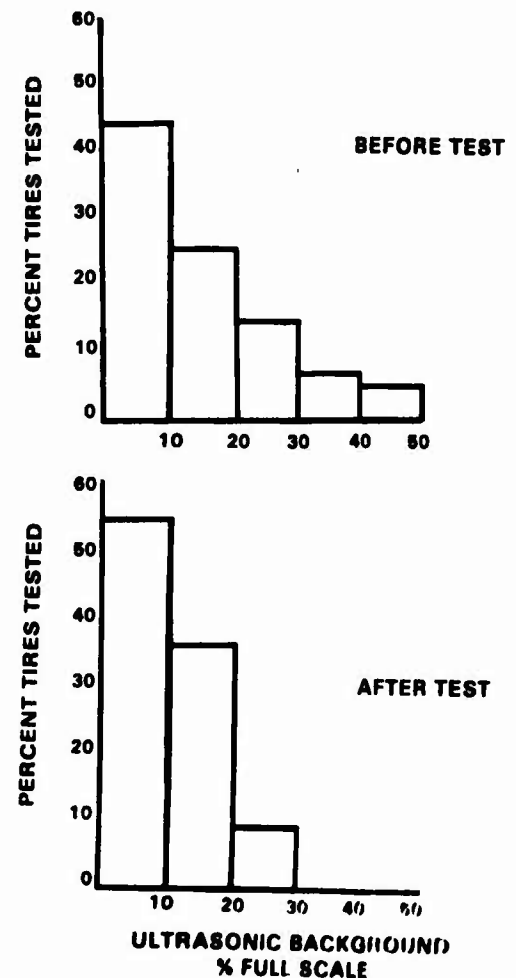
Figure 5. Percentage of 1100 x 20 retread tires versus ultrasonic background reading.

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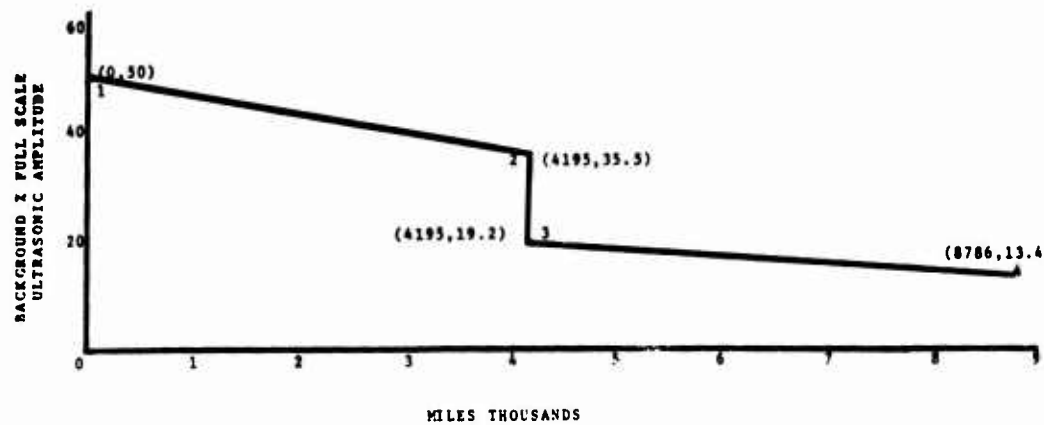
Figure 6. 1100 x 20 tires average background reading versus average mileage.

retread tires. The most revealing portion of the graph is the vertical drop shown by segment 2-3. This drop represents degradation during the retreading process. However, this drop is not as drastic as shown in the graph due to the fact that points 2 and 3 are mutually exclusive (i.e., the tires used to determine point 2 are not the same tires used for point 3) and the fact that experimental error was introduced because the retread level of the tires was unknown (a second or third retread would have a much lower reading than the first).

Of the total population of 1100 x 20 retread tires checked ultrasonically, 63% failed during the test. Figure 7 shows this failure data plotted versus the ultrasonic readings taken prior to testing. This is shown as the probability of wearout (i.e., success). As the amplitude of the background signal increases, the probability of reaching the wearout point increases.

CONCLUSIONS

The results of the ultrasonic portion of this tire test showed that:

a. Tire cord condition (i.e., degradation) can be measured.

b. The pulse-echo technique can be used to evaluate the internal changes in a tire due to retreading.

c. The condition of the bond between the retread cap and tire casing can be evaluated.

From the data, it is concluded that ply separation alone cannot predict remaining tire life. Instead, the condition of the tire cords (degradation) and in retread tires, the condition of the retread bond line, are the indicators of expected tire life.
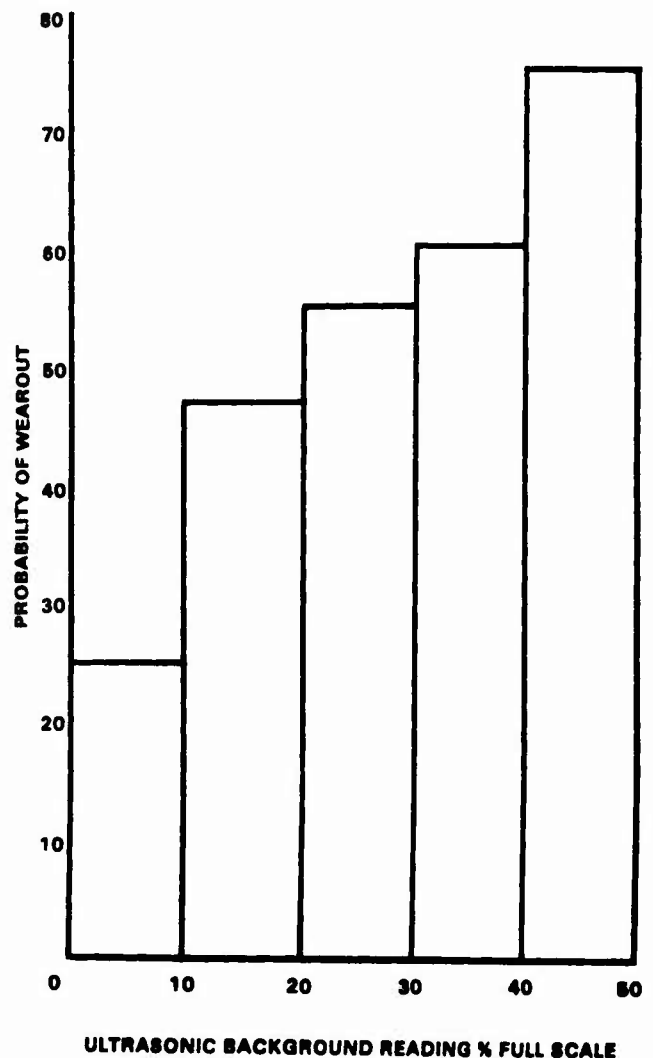
Figure 7. Probability of wearout versus ultrasonic background reading.

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HOLOGRAPHICS VERSUS ROAD TESTING

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Product Assurance Directorate
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The Army conducted a tread wear test of its more widely used truck tire sizes at the Yuma Proving Grounds from July 1974 through May 1975. Yuma was chosen because it was felt that the conditions there were some of the severest that can be found. It should be noted that our study placed emphasis primarily on the retreaded tires that were tested. It is from the retreads, the Army feels, that the greatest benefits from nondestructive testing can be obtained. The sizes tested and the vehicles on which they were placed were: the 700 x 16 tire, used on the jeep; the 900 x 20 tire, used on the 2-1/2-ton truck; and the 1100 x 20 tire, used on the 5-ton truck. The test consisted of four 3000-mile cycles for the jeep and four 5000-mile cycles for the 2-1/2-ton and 5-ton trucks. The cycles were divided in the following manner; 60% paved road, 20% secondary roads, and 20% cross-country roads. Various loading conditions were placed on the vehicles with lighter loads being placed on the cross-country portion of the cycles. Every tire tested was first examined holographically. After testing was completed, a second hologram of the tires was taken. The data obtained from each hologram was placed on a data sheet and graphs of population versus the number of defects were produced from these sheets. From these graphs it was hoped that trends would develop to predict the life obtainable from an examined tire.

A commercial holographic tire analyzer, the GCO-AT-12, was used to examine the tires at Yuma. The examination process of the test tires begins when a tire is spread by mechanical fixtures in order to observe the inside of the tire. At atmospheric pressure a quarter section of the inside of the tire is illuminated by a laser light and a photograph is taken. The tire is then subjected to a vacuum and a second photograph, actually a double exposure, is taken. The vacuum creates a stress which causes a very small displacement of the inner surface of the tire in the area of a void or separation which results in a fringe pattern on the holographic film. The result of these two exposures of the same area under different stress levels is a single holographic picture of hologram. This process is repeated until all four quarters of the tire have been holographed. By reilluminating this hologram with laser light in a holographic reader, defects under the surface of the tire, such as carcass ply separations, belt edge separations, tread and sidewall separations, porosity and voids, carcass and belt damage are revealed. All of these defects were recorded on a holographic data sheet.

The data obtained from these data sheets were assembled into a population distribution graph. Using the number of defects found in the initial holograms, Figure 1 shows the population distribution of the defects and the average mileage obtained for each grouping of defects for all the tires that were tested and failed in other than a wearout failure mode. From this graph, predictions of the average mileage obtainable per number of holographic defects may be discerned. It is important to note that there was a problem in assigning a numerical value to the weak, suspicious and degraded areas. Tires with these areas make a significant contribution to the total population. They, in fact, make up nearly one third of the 900 x 20 tires and nearly one half of the 1100 x 20 tires that failed. Thus, it can be seen that the numerical value assigned to these areas will influence the total number of defects assigned to a tire. This in turn will affect the grouping in which the tire will be placed and the average mileage of that grouping.

Figure 1

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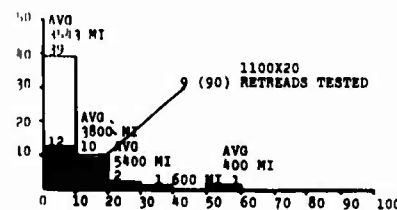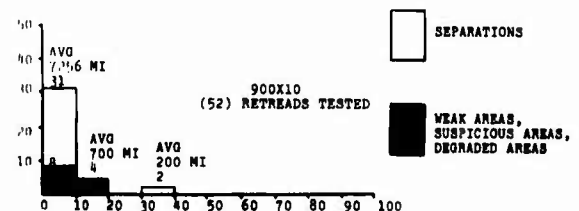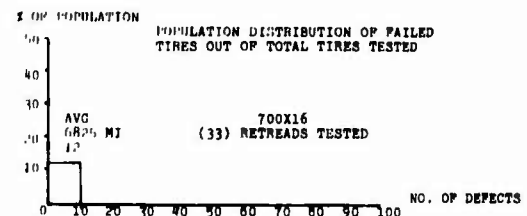
Keeping that in mind, a general trend appears evident from the tires that were tested and failed. The general trend of the greater the number of defects, the greater the probability of tire failure seems to hold true for the 700 x 16's and the 900 x 20's and loosely for the 1100 x 20's.

From all the data studied it seems apparent that the holographic technique of inspecting tires does an excellent job of discovering separations and voids. As far as other defects are concerned, additional refinements in interpretative technique or equipment appear necessary.

When voids or separations are discovered on an initial hologram, there are several possible outcomes. The voids or separations may "grow" and lead to a premature failure or they may remain the same size and have no effect on the life of the tire. This problem of separation growth as tire mileage increases was addressed in our study. It seems apparent from our investigation that not enough is known about this phenomena to determine the mechanisms for separation growth. Some tires that were apparently sound developed rapid separation growth and other tires that were under suspicion had little to no separation growth. Thus, the presence of separation is not always an indication of tire degradation.

Several of the test tires were sectioned to compare actual defects with holographic indications. In all cases, the holographic defects identified as separations were found physically to exist either at the tread rubber-ply cord interface or separation within ply layers. It can then be concluded that where holographic film indicates a separation defect, a separation defect in fact does exist. However, the nature, and criticality of the defect cannot readily be ascertained from the holographic film.

Thus, it seems that *major* separation defects are detectable and can visually be proved to exist. As to these separations, no definitive answer can be given as to their potential to shorten tire life. The weak, suspicious and degraded areas add difficulty to interpreting a hologram which in turn adds to the difficulty in determining their affect on tire life. Finally, a question arises in regards to those tires that are apparently sound with no holographically detectable defects failing prematurely. Part of this could be answered by the fact that the holographic technique cannot detect all defects leaving such defects as ruptured cords and permeable inner liners undetected. Another part of this same problem may be that there are minor defects that are not detectable by holographic techniques, as they now stand, that lead to premature failure.

Thus, it seems that more experience may provide new interpretive techniques to solve some of these problems. As it now stands, much more work is necessary before a commercial version of a holographic inspection system on a production line basis, could become operational.

QUESTIONS AND ANSWERS

Comment: I just want to bring up one point. I think it's kind of important that we had this meeting. There are three people involved in the commercial production unit for ultrasonic testing and none of the systems that are really in this commercial program are represented here. We have Admiral, we have Automation Industries, we have Brannick, all in process on the through-put machine similar to the one at NHTSA which I think is of interest to all of us refitters. I was a little disappointed that somehow or other we didn't get a few minutes to spend on this type of device and talk about the development work.

Mr. Vogel: We thank you for that comment. Mr. Merhib is going to mention the purpose of the working groups a little later on this morning. All I can say as my personal comment to your statement is that Mr. Van Valkenberg has spoken for Automation Industries at the last two meetings and both of the other manufacturers were solicited for papers. Now, I can only go so far, - I can't force them. I can ask them and I can ask you people as the users of this equipment to lean on your suppliers to get papers. I've taken every possible effort I can to roust out papers and the chairmen of your working groups and Mr. Trevisanno as well as Mrs. Earing in the infrared industry have gone out and asked their principals or their contacts in infrared to get out papers. Well we can't. The person they're building it for isn't ready to have it publicized yet, and this is the thing we run into constantly. If Mr. Firestone and Mr. Goodyear have an item under development, he can go to a supplier and say "Okay, you have a release, give a paper but don't squeal about this aspect of it that we don't want publicized." I really don't know how to answer your question except to say that we tried. We went out into all the rubber publications and we went out through ASNT, all of the builders of nondestructive testing equipment and in my capacity in ASNT I know all of them, written to them all personally, and contacted friends. The program you see has all the papers that we were sure were not what you might call crass commercialism. I mean, some people did want to get up and give commercials. We can't have that. We would like to give technical papers, not just a sales pitch. You get that around the trade shows. Go out and try. Give us the papers and if it's not too hard a commercial we'd be delighted to put it in the next program.

MAINTENANCE EXPENDITURE LIMITS BY NDT

Dr. R. N. Johnson
GARD, Inc./GATX
Niles, Illinois

Primarily what I'm going to discuss is the program we have currently for the Army which is called "Maintenance Expenditure Limits of Tires." The basic overall objective of this effort is to develop data and procedures necessary to implement the tire degradation monitoring in the Army system. It is basically: what "accept/reject" levels does one use for each geographic region to obtain the maximum benefits of the system. Split it through several different sections; one will admit that the first area we will encounter were the review of the previous programs we had which led into this. One is what is the effect of water on retreadability - if you use water in the ply sections. The second area of discussion will be the examination of whether entrapped moisture is harmful to tire performance, it's the road test we use down here, and the third area is the result of a survey taken to determine the geographic variability of what we choose to call tire degradation. The last thing I'm going to cover is the simplified example of how you can use this kind of a model, you can save a lot of money when you are managing a lot of tires.

Mainly what we have is a nice collection of cut tire sections for a variety of military tires that are soaking in a fluorescein dye water solution. We took a variety of used tires of the military that had been rejected for various reasons, soaked them from two days to sixty days just to see which ones would absorb water through the cut sections on each one of these tires.

After the sections were done soaking, we proceeded to subdivide the sections into smaller sections and examine each one under lights so that the fluorescent dye would show up in the cords. In a typical cut section, you would see here light areas of the fluorescein dye. If the dye had not penetrated into the cord, the cord structure would be dark, and some of them have cord areas which don't show up because they don't glow with the fluorescent dye.

We did find that a number of tires would absorb water after soaking like this. It turned out from our samples of military tires, almost 100% of the rayon tires would absorb water quite readily, and surprisingly about 10 percent of the nylon tires would absorb water. We at first thought maybe it was the manufacture, a peculiar cord type, or something that was tied with the nylon that could absorb water. We examined that and couldn't find any underlying basis for that.

There were different manufacturers, there were different sizes of filaments in the cord bundles - nothing uniform about why they would do it.

We did at this next step look at it and see in terms of retreading application since the worry was if you would absorb water into the plies and the person proceeds to buff the old tread off, rebuild a new tread on and send it out to service, you have some trapped moisture in there, the temperature goes up beyond the boiling point, you're going to turn that trapped water into steam and create separations. The idea was in the case of how does one in terms of retread inspections find out whether the tire actually has water that has been absorbed into it. So we looked around and we found a gadget which is actually used in the wood industry to gage the moisture content in wood at lumber yards to find if it is sufficiently dry to sell to customers so when you build a house your house doesn't need to be crooked, and we found that this actually works quite well. It has a handle with the two needle probes on it and you just insert that into the tire right around the cuts and you can very accurately come out with moisture penetration into the tires from cuts. It's very easy for the liner side so that when the inspector is making his normal liner inspection prior to retreading, he can have a gage like this available, battery powered, the thing is not fairly economical - these gages cost anywhere from $100 to $150 each. You would have to have it calibrated for tires because right now it is calibrated for wood.

The next idea was to find out if there was any way you could predict which tires would absorb moisture. We found that we would cut these tires and we asked ourselves as long as we were doing ultrasonic stuff on the side is there some underlying characteristic in these tires that causes that - the moisture penetration would be detectable by ultrasonics. One of the reasons we felt this way is we sectioned a variety of tires; we looked at them under the microscope; we looked at them under an electron microscope and we find that there are sort of subjective differences between those that would absorb moisture and those that would not. It's obviously not the kind of thing you could use because it's destructive to cut holes in your tires. But we felt that since there were these current structural differences, between the type of tires that would not absorb moisture and tires that had the cords that would, we felt that ultrasonically there

ought to be some way of determining that. So we investigated a variety of those that would absorb moisture that we had found in previous testing and those that would not. We noted some characteristic differences in the signals. We then proceeded to check that by going out to a trailer load of new military tires that we had and picking out the ones that we felt would absorb moisture based on an ultrasonic reading taking them back in, sectioning them, and soaking them. We did find that indeed we could predict those tires ultrasonically which would absorb moisture. That led next to the logical question; are there any mechanical differences between tires that would absorb moisture and those that would not. We then proceeded to start sectioning these tires and doing peel tests and cord-stripping tests on these tires - what we call the hydroscopic tires as opposed to nonhydroscopic tires, and we did indeed find that the hydrosopic tires are weaker than the permitted peel strength levels and are indeed weaker than average population of tires in terms of cord strength. This led us to presume at that point and that they probably would not do quite as well in performing their intended function that is, putting them out on the road and using them as a normal tire. At this point we started going over the tire degradation and doing the road testing and Yuma started monitoring these tires and seeing how these signal characteristics would relate to road testing. And that was described by Leo, Dave, Brian, and Joe earlier so I won't go into that result.

The next step we took in these studies was to go out and actually survey, thinking now in terms of moisture that gets into a tire. I've surveyed a lot of tires at various military installations that they had to see how many injuries cut into the tire, actually had moisture around them. We had one survey done in Arizona, Louisiana, around the Chicago area, out on the east coast, and Virginia. We found that about one to five percent, depending upon which geographic area you were in, of the tires had injuries which had moisture associated with them and we could find moisture penetration into the tire 1/2 inch or greater. Some of the cuts were so large that obviously the tire would be scrapped anyway and would not be retreaded. We did find that anywhere from one to three percent of these tires that had moisture-effected injuries would actually slip through the inspection system according to the Army standard specification for "accept/reject" injury sizes and cut sizes. Which basically says that you are allowing a few tires into the system that do have moisture effected defects, which give you injuries larger than they think you are and actually form the basis for initiation separations. The other bad thing about looking at those tires that do absorb moisture, are also weaker tires to start with, so they are bad candidates to have weakened in the first place.

I just might add here that the engineer taking this test, that ultrasonics doesn't really cause your hair to fall out at this inspection, but we're not so certain the tires might not.

The next part of our effort after we looked at the defects, found that they exist in the real world, with moisture in them, is to take them out on the road and find out how high the temperature can go in a tire that's in actual use. We've seen a lot of people do dynamometer testing to find out how the tire temperatures vary, but we actually wanted to see how they vary on the vehicle in an actual terrain. Basically, we took a jeep tire, instrumented with five thermocouples buried into various portions of the tread. One of them was on the inside liner on the midline, there was a thermocouple on the sidewall, a thermocouple buried halfway down the tread, and thermocouples in the shoulders. We then proceeded to take the jeep out on test runs in the desert. Now the way the transmitting is done, the thermocouples are fed into an FM system and the data is transmitted actually from the rotating wheel into an antenna along the side of the jeep and fed into an FM reader and then comes out digitally, so that we could actually find out what the temperatures were as were traveling real time.

We charted a run of a jeep which basically had two passengers and no other load. The outside temperature at the time of the test was 110 degrees. This was a 50 mhp highway run. The tire I believe was mounted in this case on the front right position. We did try rear wheel positions, left position, to see if there was a diffference from right and left positions from front to rear to see if there was a difference from front to rear in the temperatures generated by the tires and indeed there are differences.

The first run charted is going out along the stretch of road out 40 minutes which is about 30 miles. Then the jeep is stopped, we examine the thermocouples to make sure everything is in place. Then we turned around on the stretch of highway and came back. Interestingly enough here you see that the run out is a little bit cooler than the run coming back. We have theorized that on the run out the wheel was in the shade and on the way back the wheel was in the sunlight. We do find here the thing to look at is primarily along the midline where we had - this tire was selected to be a hydroscopic tire - the tire that we instrumented - we actually injected water into the tire. We then put a thermocouple next to the injected water area, and we wanted to see whether that water area would indeed get up to 212 so we could predict whether the water in there would turn to steam. We did find as we took it out after about 30 minutes into the run, indeed it did hit 212. And we feel like in this case we didn't go up

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above it because the water is kind of turning to steam that it absorbed a lot of heat into the system, so it absorbed most of the heat beyond that. But is does say that the moisture-effected defect you can see road operating temperatures that are that high and will turn the water in those defects into steam and can form a potential separation, especially concerning the nature of the tire that tends to absorb moisture.

We then loaded the jeep up with the stated loads that the Army uses out in Yuma. I believe it's 800 pounds they put into the jeep. We took it the same highway run on the jeep and we didn't plot all the data in this particular try, but what I want to show you is the thermocouple that was on the midline that was very close to a liner. The temperature of that climbs slowly up beyond 212, went up to about 240 and suddenly jumped up to 350 or so and then leveled off at about 360 degrees. Away from that area further down into the plies you find that the temperature is steady at about 170 degrees. So our suspicion is what we're seeing is that the scuffing of the inner tube on the tire liner is localized friction and that builds the heat up. We added innertubes in these particular tires so we didn't suffer a tube failure but that's obviously a consideration if you're going to heavy-load vehicles with tire with tubes in them. You can't keep very high temperatures with scuffing action.

In the surveys we're doing, locking for defects, we also wanted to survey those areas to see what the ultrasonic characteristics or the degradation characteristics were of the general population of tires in those areas. We primarily were interested to see how the real world behaves in terms of degradation is compared to the Army tests at Yuma. And so we ran to different geographic regions, we picked different sort of extremes to see this quick and dirty means how tires behave in real life and it's very economical as compared to doing road testing. For hot dry in Arizona, results from populations - these were not Army road test tire populations. In each sort of an ultrasonic category, the category running between 0 and 100, the lower the category the greater the amount of degradation. In this test we saw 55 ran into the very low 0 to 5 category. A new tire, we prefer to see in the 50 percent region so in this case these are actually severely degraded tires so that the use in Arizona is very hard on tires in terms of degradation.

The next test was in cold-moderate climate - the moderate refering to moisture amounts as we were big on moisture at that time. We rated the water availability and the temperature. This cold-moderate test was actually taken in Anchorage, Alaska on tires that are used in Alaskan environment only. You can see that it is not quite as bad as the Yuma results, they're not completely

over to 0, but you still find a very heavy preponderance of tires in the lower regions, which says again it's a very harsh environment for a tire in terms of degradation. I am taking you in order from the worst to the least harmful environments. Alaska would be rated as the second most harmful compared to the dry desert which is a very abrasive type.

The next set of statistics are from the hot-wet results which is in Louisiana. There is still a shift to the lower regions of the results considering we've had a hot-wet and a hot-dry does tend to say a lot about the heat which is probably a big factor in causing the degradation. In Alaska it's not clear if its the extreme cold causing the degradation or the very abrasive nature of the terrain. They have gravel roads and that type of thing. But we do again find this skewing over the left of the schedule.

In the Virginia survey, run on a moderate-wet retread area in Virginia, again we found a lot of tires in the lower region. It's not as bad as Louisiana, or as bad as Alaska or Arizona, but it is fairly bad. But one thing that I might mention as we've done this sort of statistic is to find out how many times a retreader is getting a bum rap when he has a lot of problems with his tires. When he keeps getting a lot of tires out in the field his customers come back and say "you guys are doing a rotten job of retreading." We wanted to get a sort of feeling really if it was the retreader causing the problem or are some of these guys were getting very bad casings to work with strength-wise. We do see the differences here so it is quite possible that a retreader can get blamed for things which are truely not under his control. In other words, if he has quite a captive user and the user goes about and uses the things in an environment and a situation that produces a great amount of degradation in the tires in his use. He takes them back to the retreader when the tires start failing on him and says to the retreader "you're the one who's at fault." Well, with this kind of thing the retreader will say "oh no! it's the tires you supplied me with and if you're going to supply me with these kind of casings, you're going to get this type of result." So it has that kind of an importance.

The last case we have is actually a Chicago result, and had a very great amount of difference between them. This is sort of urban driving around Chicago taken in Fort Sheridan, probably on a multi-paved street, probably not too much high speed driving, and no real great temperature extremes. We don't know too much about the nature of the use of the vehicles whether they are heavily loaded or not heavily loaded. But we saw there a completely different background reading than we find anywhere else.

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Given the existence of another kind of a curve, we wondered what does that mean in terms of economic benefits for the user. So we started a little bit of playing around using this kind of logic and could obviously see the capability to predict. The capability to predict gives you a great tool to make some very nice economic decisions in managing tires. For example, if I am a retreader and I get a tire in my system that reads in this category down near 0.10, I can say "I don't want to bother retreading that thing because the guy who puts that out in the system again is not likely to go anywhere, it will fail on a 1,000, 2,000, or 3,000 miles and I will have wasted the money I put into retreading, and I will have wasted the guy's effort in mounting and demounting the tire, and I'm also going to have the problem of accident potential and this type of thing." But if I find a tire up in the high region, I'll say "that's great, that's really a nice tire to use again, and that's a tire that will take an economical retread."

To give you an idea of some sort of the logic you can run through, take a 9.00 x 20 tire size, in this case it's a military size tire. The average military cost to retread is say $37.00, the new tire cost is roughly $52.00. We threw in arbitrary factors just for practice. You might complain about these things. You might say that there are $5.00 of these costs involved in transportation, inspection, and paperwork, $15.00 labor in the person's mounting, demounting, inner tubes, valves, etc. The retread cost breakdown is 64 percent for materials, 17 percent for labor, overhead 19 percent; tire loss at the buffer. If you lose a tire at your buffer, if the buffer detects a separation you haven't invested very much in a tire at that point so in materials you haven't lost anything because you haven't put any materials onto it yet, or maybe you've lost a couple of bucks on the handling of the tire up to that point. Overhead at that rate would be $2.30, handling would still be $5.00, you've lost $9.30 on a 9.00 x 20. If you lose the tire on the molder because it's degraded and it blows out at the molder, you've already put your tread on it which you've paid your exise tax on and everything. So you may have lost $24.00 in materials, $5.00 in labor since you've processed it a little bit more, overhead's a little bit higher up to that point, handling is the same, total in that case is $37.50. If it gets through the buffer and the molder but fails in service, you find out you might have the total investment of the $52.00 + $15.00 + $5.00 for handling now that you've invested in the tire. The only way you're going to get that back is to get out the prescribed number of miles out of that tire. In the case of the military they strive for 15,000 miles, so any miles less than 15,000 that it goes is actually going to make that

tire more costly to run so we developed a little simple relationship take 15,000 minus the miles driven over 15,000 and it gives you the proportion of the money you're going to get back out of your $72.00, and that will give you a feeling for your losses that you're going to take there.

To carry this thing forward, based on averages, you might lose 3 percent of your tires at the buffer, 3 percent at your molder, these are more of less representative here. You might lose 20 percent in-service carcass failures. Now this is based on road test results that Yuma had - 20 percent of their tires were failing. The average was 7,000 miles rather than the programmed 15,000 miles. You had a few that are due to road hazard failures at 7,000 miles. You have 54 percent that survived to 15,000 miles test. If you assume in the case of the Army that they do 43,500 9.00 x 20 tires annually, you can run through a calculation and see what costs potentially you can save if you can prevent particularly the 3 percent buffer loss and the 3 percent molder loss, which we think we can do. And a lot of the 20 percent in-service carcass, we're going to assume we can prevent 100 percent of it. But whether we can or not we're going to have to find out. If you run through these calculations, you can see you save $12,000 at the buffer station, by keeping the molding losses down you can save $48,000 a year, and by running through the in-service losses you can save $330,000 a year, or a total of $390,000 a year savings by implementing a pre-inspection based on degradation.

For sort of a presentation of logic a person can play with in terms of cost per mile to drive the tire. You get sawtooth type of curves that you can go through as you run a tire out. Actually, the more miles you put on a tire the cheaper it becomes to run. You invest the whole bit in a repair, that raises the cost as you run it out, the costs drop again, maybe you do a repair on it. Otherwise you might compare it say to a radial tire which goes a little bit further before wearing out, it costs more but then you get more miles on it. If you can invest in the cost of a retread, it goes again, you can do cross-comparisons between the tires. Based on this kind of an ultrasonic logic, if you can generate curves like this, which is what we're in the process now of doing for the Army.

So that basically is a summary of some of the things we're doing, and a hodgepodge of some of the things we have done in the past. We talked a little bit about the water type of defect at the last meeting in Atlanta so I kind of slipped through that quickly rather than dragging it out.

Are there any questions?

Q: On the 7x16 jeep that you were running, what was the actual percentage of rated load under the TRA?

A: When they ran them at 800-1b loads, I think its the maximum load, they...Questioner cut in: That was the Army, but compared to the Tire and Rim Association load max what was your load?

A: I can't answer that, maybe 1100 on the vehicle.

Q: On highway at 800 or cross country?

A: We were typically experiencing around 750 lb. per wheel in the front and around 850 (in the rear in Chicago.

Q: The Tire and Rim Association says somewhere around 1700 lb. maximum per tire.

A: That's about right. You can run about 50% total load.

Dr. Ryan, Q: Regarding your cost per mile, is that the cost average for total mileage up to that point or is that a differential cost? It's very confusing, it looks as though you're getting a cheaper cost per mile out of new tires than you ever get out of retreads.

A: Well, you might actually. The costs become what you've invested in the new tire because, say we invest $100 and we drive it one mile before it fails, it costs us $100 a mile to run it. But if I run it 10,000 miles, then the cost to run it is down in the cents per mile category, a penny a mile.

Q: I can't understand that 15,000 miles average wear on a tire. Is that on a real rough surface?

A: The reason we picked 15,000 miles is because that's what the Army specifications says they would like. They purchase tires that supposedly will last 15,000 miles regardless of where they are used, and actually in the tests that were run at Yuma, those tires that did complete the test were capable of going 15,000 miles.

Q: You're talking worn out at 15,000 miles?

A: You have two things working against you, that's a very harsh environment to test tires

and I think that the Army pattern which they use is not something that guarantees you a long life. I think your lug pattern is not a long-life tread pattern. They don't have the lug pattern for that reason.

Q: In using your water penetration meter, is that destructive or do you have a way of patching up the holes so you don't get damage.

A: The holes are just pin holes, and we don't find that it's a problem. As a matter of fact, part of our feeling about it is that you won't get minor leaks in good tires anyway, even if you punch holes in them. We were talking to some of the people from Firestone yesterday, and they sort of agree with that. They found that they get lots of things in tires and if the tire is good you can knock holes in it and the plies will not absorb water that easily. But once a tire has reached a worn-out stage, they will. We have seen water go through liners on tires when the liners were totally intact but had very small pinholes. You could smear some kind of a rubber paint over the liner I would expect.

Q: What is the source of the water gage?

A: The name of the thing I was telling you about just escapes me. The company is in New Jersey. It's a wood gage. There used to be one made in Germany but it's no longer made so we had to search for an equivalent. This one is nicer because it has a meter so you can actually make your own rating without being stuck with the manufacturer's. One tire supply has listed a gauge available in their catalog that basically operates the same way for moisture detection but I think that primarily theirs was for surface moisture detection. They wanted to make sure the surface was dry before one put adhesive on it. But they haven't brought any into the country for the past five years. So we shopped for an alternative supplier and that's where we ran across the wood industry's meter.

CHAPTER IV - WORKING GROUP REPORTS

INTRODUCTION

Charles P. Merhib, Moderator
Army Materials and Mechanics Research Center
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Mr. Merhib: (Gave concept of Working Groups and their locations, and introduces the chairmen.)

Mr. Merhib: Mr. Bob Yeager of Goodyear has a comment to make on the papers given and also on attempts to get papers.

Mr. Yeager: I would like to commend many of the people who presented papers this morning, but I felt that many of the papers fell short in that I didn't understand exactly what they were trying to get across. You can't separate tire degradation from nondestructive testing, or attempt to define tire degradation without knowing what the stresses are in the tire itself. We have been working on holography for about five years. We have, we feel, the best system in the world to date. We do measure nonuniformities. We have been accurately measuring anomalies and separations for four or five years on thousands of truck, aircraft, and passenger tires. We are working on building some ultrasonic units ourselves, plus many other machines to observe stress patterns in a tire. But coming back to defining degradation, when you talk about degradation you must determine whether it's a bias, belted or a radial, whether it's a steel-belted radial or glass-belted. When you're talking about degradation are you talking about the glass fatigue due to bending, due to compression, or due to changes in stress, or are you talking about about the centerline of the belt or the edge of the belt, or are you talking about the underlying shear strength between the belt and the carcass, between the wire and the coat-stock - just where are you testing for this so-called degradation? We are working on this tremendously, and welcome an attempt to work with you on a cooperative basis. The atmosphere today is not conducive to giving papers and giving information out or stating facts which can be taken out of context and be used against us. But we'd like to invite you to look at this on a cooperative basis. I believe we do have some knowledge which would be beneficial in getting you pointed in the right direction. There's no reason for you to worry about economics at this point. When you don't have the basic knowledge, you're going to spend the next ten million dollars just getting to what is already available. A few of the many types of degradation can be catastrophic. Some types of degradation in tires we have found do not mean very much. I don't think you can say that any correlation programs that you have presented in the past have worked, or have very much practical value. I haven't yet seen a piece of equipment that's really practical. When you talk 100% inspection of tires or even a quantity approaching that, we think that you must have a much more thorough and broad knowledge of tires in general. We invite the cooperative spirit to be once again adopted between industry and the Government so that we can forge ahead together in these areas rather than duplicating each other's efforts.

X-RAY

Ted G. Neuhaus
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The X-ray group met for about 1-1/2 hours. I think the reason for this was that X-ray has been established as pretty well developed, there are new items that we'd like to be seen on the systems but I don't think we have too many details to discuss.

I think it was pretty well established that X-ray is here to stay, it's a well established and accepted technique, it's pretty well advanced and as I said, the state-of-the-art is developed. Our major problem in the X-ray area was materials handling, conveying the tire, conversion from the laboratory atmosphere to production. We posed a problem to the audience as to what new items would like to be incorporated in new systems. As usual we had the same comment, the unit price is too high, and, of course, the reason for this is that the volume at this point is not sufficient to decrease the cost of manufacturing. This is a common question; I've heard it for the last three years.

The general opinion was that there is a lack of automatic image analysis. In other words, at this stage the operator is still the grading mechanism; his visual interpretation of the image. In order to increase the volume usage of X-ray systems today, automatic image analysis is required. Also, the discussion of the new fiber B, the Kevlar, the general concensus was that the Kevlar imaging still was not good enough, it could be better; and, of course, faster inspection comes from better resolution to the viewer. There was a suggestion made relative to Kevlar that we add or change the chemistry, add some opaque material to the core to enhance the contrast. Of course, this is a continuing problem that chemists resist in the tire manufacturing process. It was agreed that there was a need for a low cost mobile semi-portable X-ray system to check green tires at the building location. The primary check on this type of machine would be to verify location of belt. It was agreed that the number of cured tires inspected still is in excess of green tire inspection. However, green tire inspection is still important. We asked the question, "will X-ray inspection increase in new tire production?" And, of course, the general answer was only if the original equipment or government dictates this 100 percent inspection. Presently we feel it is a process control check method. Also, we had a question come up as usual, "should we combine X-ray with the uniformity process?" And again the answer to this was that it would be better to separate the two processes.

Belt inspection only is a thing of the past. The machine capability of X-ray system should be able to view bead to bead. We also agreed relative to automatic imagine analysis in replacing the operator that it was possible with the present state-of-the-art to automatically measure spacing and sidewall steel tire construction. This would be done automatically with solid state detectors. In addition to the solid state detectors, you would still be required to view some type of video image. Not putting in a plug for X-ray, but I must admit that most of us are biased. To date, we feel that X-ray is the best overall method of inspection. It's the most comprehensive to the builder, it's the easiest to interpret to the general working man within the tire plant, and we have agreed that probably we have the most installations of this type of inspection today.

It was pointed out in the meeting, six years ago, that X-ray systems were installed quite heavily in the tire plants, and the scrap rate dropped from a 10% figure to 4% with the builders. It was somewhat of a psychological effect and still a very good method in this respect. Also, it was pointed out that new tires today are inspected primarily for constructional control, but also we look for the defects other than the symmetrical uniformity changes. That's the end of my report.

ULTRASONICS

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Approximately 40 people participated in the Ultrasound working session. I regret that much of the subject matter covered was not introduced during the general paper presentation period. I think there was a lot that might have stimulated further discussion on the floor.

Let me go over major things gone into. It started off with a review of the principles of ultrasonics for tire inspection, and we compared thru-transmission and pulse-echo principles and capabilities, talked about sensitivity, some of the recorded results from the Australian efforts with air-coupled through-transmission ultrasound, Dr. Ryan's experience at DOT, some of my experience with aircraft tires, and General American's with the Army tires. There were a number of questions - unfortunately there were a lot more questions than answers, and we're kind of used to that. There were questions about pattern recognition for degradation measurement. What corrections are necessary with tire construction, type of material, temperature influence, cord size, things along those lines? What calibration standard is realistic for the recognition of degradation? What is the repeatability in the experience that has been gained so far? I think in the limited area of application to date that these questions are quite a problem. General American has made calibration standards using sections of a tire for standards, and they feel that their equipment repeatability is good. Nevertheless, nobody feels they have a good hand on degradation and there is much more needs to be done. The differences between American and Australian emphasis in through-transmission tire inspection equipment use and results were discussed. The Australian people feel that for their aircraft models and for their type of use that they are very successful in operating performance of their retread tires. In this country we do have some added activity but we have not seen any major application or development since the last meeting. We talked about the fact that ultrasonic equipment appears to be highly product or problem oriented and that it may be that many variables will decide a system for a particular problem or product. There was information supplied that a laboratory study by Fabric Research Company in Massachusetts had developed some

explanation for fatigue; they had cut tire sections and fatigued them and then studied them microscopically and performed critical tests, and this report is available from Fabric Research Company.

A question came up about what variable in a new tire is indicative of quality. And although there was another similar question that we didn't get around to, general concensus is that there may be some intuition experienced on answers and that we need industry cooperation in getting to the bottom of these questions. We feel that the meeting generated developed additional cooperative effort between the working group participants.

We got a little bit into other applications of NDI two-level products and a little bit of discussion about aging. Unfortunately, we don't have answers to all the questions on the application of ultrasound. However, the application of ultrasonic inspection methods to the quality assurance of tires is starting to demonstrate real capability. During the first symposium, the principles of detecting anomalies with high frequency sound were presented. A second meeting heard discussions along the lines of reduction to practice. This symposium has learned a further reduction of the method to practice with combined efforts of Tank-Automotive Command and General American. We were impressed with the significant instrumentation developments by the Department of Transportation Systems Center and General American. In particular, much interest has been generated by the first presentation of information relating ultrasonic quality measurements to road performance. For safety reasons, and for cost and energy savings, the ability to predict tire performance by degradation classification is most attractive. I took advantage of this opportunity to review current ultrasonic programs and proposed efforts. I am pleased that I have heard so many complimentary remarks about the conference. Some of the people who have real problems with tires are becoming leaders in nondestructive inspection. We are working together, and application studies results have stimulated reaction across the rubber industry and numerous cooperative studies are being formulated.

We found that the critical sounding remarks delivered by one attendee during yesterday's general session were very constructive. However, some Government members and equipment manufactuers feel that they are not receiving sufficient assistance and participation from the tire producing companies. We realize that we are far from answers to questions in many areas. You must appreciate that funding limitations seriously restrict timely progress. A few good people can't resolve everything overnight.

In response to the question, "shall we hold a fourth symposium?" We had unanimous agreement that we should in about 1-1/2 to 2 years. To Paul Vogel, and the hosting activity, Army Materials and Mechanics Research Center, we thank you for another excellent symposium.

INFRARED

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B.F. Goodrich Company
Brecksville, Ohio

Infrared has not proved to be effective for the nondestructive inspection of tires in the same sense that X-ray, ultrasonics, and holography have been. Infrared does not have the sensitivity of these methods for detecting small flaws in tires. The technique of passing a heat flux through the tire and looking for flaws has been tried. But this method is too slow, and is not sensitive enough to detect small flaws with the low-conductivity materials which make up a tire. Attempts have also been made to heat the tire internally by rolling it on a roadwheel and looking at the temperature pattern generated. This method has not yet proved to be successful for detecting small flaws for short tire heating cycles, but may still be workable eventually.

Infrared does have some unique capabilities which may be useful in detecting tire performance factors which are not detected by other NDI methods. For example, variations in material processing, compounding or cure can cause a tire to run hotter and decrease its durability. This behavior could possibly be detected by infrared in a short, loaded tire rolling test, but could not be detected by other NDI methods. There are commercial infrared instruments for monitoring tires during roadwheel endurance testing to detect the initiation and growth of flaws. This is an NDI test in the sense that the tire does not have to be destroyed to find the flaw, but it does involve testing the tire until some part of it has failed. It is a useful research and development aid. Infrared has also been used as an aid to tire design to determine the effects of material, construction and operating parameters on the operating temperatures, and therefore the durability of tires. Infrared has also been suggested as an on-board detector for underinflated and overheating tires. Infrared instruments are probably too expensive for this use and would present maintenance problems.

In summary, infrared does not appear to have the potential for a fast production line NDI method to detect small flaws in tires in the sense that X-ray and ultrasonics can be used. It does not have the sensitivity for detecting small flaws that holography has. But infrared may have the potential for rapid detection of factors affecting tire operating temperatures that none of these other NDI methods have. The greatest utility of infrared techniques in tire work at present is as a research and development tool to explore the effects of material, construction and operating properties on the running temperatures, durability and power loss of tires, and to detect the generation and growth of flaws in tires being tested. Infrared appears to have limited potential as an on-board sensor to detect potential tire failure.

HOLOGRAPHY

Dr. Ralph M. Grant
Industrial Holographics, Inc.
Auburn Heights, Michigan

Twenty-five people representing twenty companies and government agencies attended the Holography Committee Meeting which lasted over two hours. Each participant presented approximately a five minute summary of his observations on the sessions held over the past two days in addition to providing us with his own particular reflections upon the overall meaning of the importance of the information gathered as it related to the specific needs of his own company or government agency. The participants made numerous comments upon each others opinions.

Our first speaker, Mr. W. C. Shaver of Air Treads provided us with an excellent summary of their holography program over the past four years, in their Atlanta, Georgia plant. They are testing up to 160 tires per day on a production line basis (on Navy high speed tires). He pointed out that, despite many disadvantages, the holography process was indispensable to their operation. He also noted that their tire rejection rate has varied between 0.6 and 13% where tires were rejected if they contained any size separation despite the fact that the Navy requires a 1/2" and larger separation diameter rejection criteria.

Air Treads would like to see cheaper and faster holography machines. Despite the fact that holography sees unbelievably small things, it has not solved all their problems and yet Mr. Shaver says "they can't say enough good things about it." He doesn't think there is any NDT process for aircraft tires which is as accurate as holography.

In a future meeting he would like to see carefully documented papers. In summary, he was quite impressed with the meeting both from an information and attendance point of view.

Mr. C. L. Swinehart of the FAA expressed great appreciation for the privilege of attending the two day sessions. He said that he had learned a lot and that he was quite favorably impressed.

Mr. E. Rueger of Swiss Air in Zurich expressed great interest in our discussions as a newcomer and mentioned that Swiss Air was gathering information to reduce tire failure problems. He found the sessions quite informative. Swiss Air has experienced relatively few failures. Despite this they would like to advance their NDT awareness and capability.

Bill Fiock of General Tire's Corporate quality control group, said he has become more aware of unique apparatus for special problems, however, he would like to see more general purpose equipment for 100% inspection in a factory environment. In summary he has seen many promising ideas and is nonetheless disappointed in not seeing the availability of high speed factory production testing equipment. He felt that the rubber companies should and could be assisting the NDT people with more specific directives, with respect to the industries everyday needs.

Mr. Dave Lindquist of American Airlines, expressed the fact that they have relatively few tire failures but that they really couldn't afford to have any failures, no matter how small the percentage. They need a tool more effective than air needle injection. He has been encouraged by what he has heard and expresses great interest in any and all programs which will help him to provide American with greater protection against loss due to tire failure. He would like to hear more about specific NDT equipment availability.

Mr. Yoneyama of the Bridgestone Tire and Rubber Company of Japan attended our session to see how American companies have been using their holography machines. Bridgestone has been an active user of holography for three or four years.

Mr. Gene Wall of The Goodyear Tire and Rubber Company explained to us that if a rubber company does their early tire development homework on a given tire properly, NDI is not as critical as some might think. When poor attention has been paid to the development of a tire, NDI becomes more critical. One must also be aware of the fact that the airlines must learn to take better care of the tires which they have. He made the point that NDI has become more critical on the newer aircraft particularly aircraft such as the 747 or DC 10 which carry more severe requirements. Load and speed requirements are more severe with each new aircraft. Better NDI is becoming more and more critical, however we should not loose sight of the fact that the early stage tire development work should be carried out with great care.

Mr. Robert Yeager of The Goodyear Tire and Rubber Company explained that holography had several uses at Goodyear both existing and potential.

It could significantly reduce Goodyear tire rejection rates by as much as 50% over the near term (6 months to a year). Even if they spend a half a million dollars for holography he felt that they would experience a definite pay off.

Mr. Yeager says holography is particularly useful to screen test tires such as the ones which are tested on their high speed San Angelo, Texas, test track. They have greatly increased the safety of their testing operations. In tire development which is accompanied by holography a better tire can be produced initially. Individual tire development problems can be more quickly resolved resulting in substantial savings.

In future meetings Mr. Yeager would like to see more on pattern recognition and interpretation of tire defects as a function of individual tire construction details. The basic concept of tire degradation should be more carefully defined and explained. Aside from new tire development he expressed the view that no practical NDI tools are available for the retread job shop. For this purpose ultrasonics rather than holography may have the greatest potential, however, no practical ultrasonics tools are commercially available for retreaders at this time. In ultrasonic test results, he says that one is really never quite sure what they have with respect to a defect despite many test repetitions. When you reject an ultrasonically tested tire you really don't know what you are throwing out. In most cases you really haven't learned anything. You have as great a mystery after you test as before you started. Some better NDI tool needs to be developed for the retread shop.

Mr. Warren Grote and Mr. John Van Hoose of Goodyear Tire expressed particular interest in the new tire development aspects of NDI.

Mr. Ed Pollard of Goodyear Tire provided us with a brief review of holography testing done by Goodyear Tire in Europe and described some real-time holographic experiments which were quite interesting.

He said that real-time holography is not practical for uniformity and strength determination which is necessary for new tire development, but separations can be found. With regard to Goodyear tire holography NDI of radial truck tires in Europe during a three-year period, Goodyear was able to improve their building machines and processes and quality control somewhere between 60 and 70%, which turned out to be of great significance to them. They didn't test 100% of their production volume but they did do a significant volume on a 24-hour basis.

In the future Mr. Pollard would like to see more explanation of holographic tests, namely, interpretation of test results.

Mr. Max Nonnamaker, who is a Product Liability Consultant found the general information to be quite interesting. He provided us with a general review of product liability cases and their relationship to NDI. He provided us with a review of the cost benefits of NDI from a litigation point of view.

Mr. Bruce Richmond of B. F. Goodrich made reference to aircraft tire requirements with respect to larger planes, greater speeds, and loads. He would like to see more participation on the part of the rubber companies. A view which was shared by all committee members.

Mr. Dale Livingstone of Air Treads, formally of Bandag Inc., had hoped to receive more training aids. In view of his direction of ultrasonic and holographic truck tire tests of Bandag Inc. over the past two years he feels that holography is definitely a superior method.

Mr. Kim Butler of Goodyear Tire and Rubber Company would like to see more in-depth technical sessions which would provide us all with a better understanding of our mutual goals.

Mr. Ed Matzkanin from the Yuma Proving Grounds requested opportunities of holography training for his people and we discussed in our group the possibility of putting together a training session.

CHAPTER V - PANEL DISCUSSION

Mr. Merhib: I would like to begin the panel discussion. Are there any questions from the floor?

Ed Matzkanin: It seems like there is one method that has not been represented here: "Has there been any work done in neutron radiography?"

Ted Neuhaus: There's quite a bit of work being done by Harold Burger, who was at one time, as we all know, with Argonne in Chicago. He's now with the Bureau of Standards and he paid a visit to us two or three months ago. As near as I can see, neutrons relate to the chemistry of the rubber itself and very attractively, I would say, as far as air and moisture are concerned. Of course, there is also the safety problem with the neutron as we all realize. I don't know that much about it. I don't think it is an item we would see out on the production line.

Dr. Trevisanno: It's very slow, also, exposure times are quite long. I had a little experience with neutron radiography and as to exposure times you're talking about several hours exposure to get good resolution because of the power required, and the availability of sufficient power.

Ted Neuhaus: I might also say that the state of the art is somewhat reduced because of imaging devices. It's very difficult to image the neutron, as I understand it. The standard imaging devices will not image as well.

Q: Dr. Grant: I would like to know, Paul, if it's in order to bring up a group discussion of the time of the next meeting and the location while we have as many people as are gathered here?

A: Mr. Vogel: To open the discussion I would say that we were fortunate to be able to get into this hotel at this particular time. As was suggested to us in the second symposium we are holding the meeting concurrently with this Akron Rubber Group Winter Meeting. We don't have a feedback yet from Jack Price, the time and place committee chairman. All we can do is get your opinions at Dr. Grant's request. There was talk of various locations, and so just for the record, I will ask for a show of hands on four of the locations that were suggested. We must stay in continental United States, and we must stay within a reasonable distance of a major airline under Department of Army directives that we not spend too much time off the beaten path. An interesting area at this time of the year, for those who are not particularly in love with snow, is New Orleans which has some major facilities in their immediate neighborhood which would be of interest, too. (Nine expressed interest in New Orleans.)

Ed Matzkanin extended the hospitality of Yuma Proving Grounds. Ed is doing some fine work at the Proving Grounds, and even though there is a lot of classified information there, there are areas that may be seen on the grounds. It is the Army's largest installation in the world covering over a million acres of the Yuma Desert. Yuma is located about a half hour by air from Phoenix, and Hughes Air West will lay on a DC-9 for us. There is a shuttle with a regular scheduled airline between Phoenix and Yuma. (Eleven expressed interest in Yuma. A vote of 24 favored Akron on voice from the floor.)

Mr. Merhib: Are there any other questions for the panel?

Dr. Ryan: I don't have a question but I'd like to make a comment that is stimulated by one of the points of interest raised, I believe, by Dr. Grant's presentation that there wasn't a thing that industry would like to see more than a versatile general purpose technique for 100 percent inspection. Our present policy at DOT is really to work toward achieving that, which leads to my personal opinion that pulse-echo ultrasonics has a great deal of potential for that. It is a very versatile technique that can be adapted to most problem areas. I probably didn't emphasize the inspection speed in my talk the other day, but the present DOT machine does the actual scanning and data acquisition in 10 seconds on a tire; that is, from the time the tire actually goes into scanning, and that could be reduced about 3 to 5 seconds so the main limitation is handling as in other techniques.

Q: You mentioned 3600 recaps. Is that all done on one machine?

A: We do not do 3600 recaps a day. I meant that there are about 3600 active retread shops. This could be from a one-man, one-mold operation, on up through a maximum production of any individual shop in the United States which is probably around 1300 or 1400 passenger tires per day. I think the largest truck shop in the States is running somewhere around 350 to 400 units.

Q: On a cost percentage basis on recap, take any given tire, run the life of it, what is the percentage of savings?

Q: Percentage of savings on retread versus new?

Q: Per mile or per landing in an airplane?

A: I'm not really qualified in the aircraft field, but in the commercial retreading field you can figure your average retread cost is going to be somewhere around one-third of a first-line new tire. The cost of a truck tire is much better. A first-line 10.00 x 20 tire is going to cost in excess of $140 to $160, and cost of retreading at the user level is going to be somewhere around $40 to $45.

Q: How does retread mileage compare to new?

A: Actually, most retreads in the commercial field will give approximately equal mileage to new. In the truck market, you can vary. There are some very good compounds out. Bandag, for instance, puts some of the finest materials into their tread stock which I think in some cases

exceeds some of your good new tires, at least on a wear level. The hot-cap retreaders are now putting on materials that are equal to the Bandag, and I believe you can exceed maybe by 10% to 15% of the mileage which was obtained on a good new tire.

Mr. McConnell: Comment: As far as aircraft tires go, we had an experience with one retread use that we kept track of. That was that we had experienced about twice the number of landings with a certain type of retreading, Bandag again, as opposed to the new tire, for a particular aircraft.

Mr. Merhib: I have a comment on the way these sessions have been run. There's no real magic formula as to how you can run several workshops concurrently and yet be everywhere at once. If any of you have any formula that would stagger or set up these workshops so that a person can attend more than one and have himself heard or satisfy whatever problem he may have, we'd appreciate it. I've also been wondering throughout the session here, on the term degradation, is there a universally accepted definition of degradation? Does everyone mean the same thing when they say it?

Comment: Just don't use the word "defect"!

Dr. Ryan: I have an opinion on that, degradation is whatever a degradation meter finds.

Mr. Merhib: If we're not talking the same language, then we've got troubles, or we are measuring different things. I do think that we should start speaking in standard terms.

Mr. Merhib: If we don't have anymore questions, I have just one more for my own interest and that somebody may care to answer: is there an NDT method that appears useful for today and another coming for tomorrow?

Dr. Grant: I think the industry is in much too early a stage to ask these questions of it, and I don't really think these issues are going to be resolved for quite a number of years to come. The answers will be significantly different dependent upon which discipline you are addressing yourself to, whether aircraft tire, truck or passenger, whether original tires or retread tires. The answers are going to be different in different cases. The basic observation that I make, not at the expense of nondestructive testing equipment, is that all of us are looking for a $2.00 solution to a very complicated problem and it is just not in the laws of physics. There are going to be many answers to many situations and those answers are going to be long and slow to come.

Mr. Jannarelli: Comment: I think it is important that the manufacturers of the NDI equipment realize the needs, the peculiar needs, of the retreader, as compared to the new tire industry where the new tire industry can do quite satisfactorily on a sample testing of a small number of samples and achieve a high degree of success in improving their product. The retreaders must

inspect every single casing that he is going to retread, and your systems must be fast enough to cope with the volume of some of the larger retreaders. We're talking about many shops in the 350 to 500 or 600 tire per day on less than a 24-hour basis. We're talking in many cases of shops that only run 12 hours, so you're going to have some pretty high throughputs. The retreader is really not expecting you to solve every one of his problems. But you're sure going to give him some help in getting rid of the big loss, I figure around 17 million dollars a year, that is caused just by casing failures.

Q: For Dr. Grant: You used the term "casing uniformity." Is there a correlation between that and tire uniformity which we normally think of as force variation, and if not, is there a means of viewing a tire force variation through holographic technique?

A: Dr. Grant: Yes, there is a correlation between force variation and holographic nonuniformity. They are closely related. We are referring quite often to the overall geometrical uniformity of the tire and then relating, as you would in a stress-strain analysis, the overall response of a ply to stress. Many of the theoretical aspects of this are still very nebulous and are in their very early stages and have not been clearly defined. But we see very close comparison to metallurgical situations, and we do see correlation with force variation, and it bears a strong relationship to geometrical uniformity, the relative placement of the various components in the tire and the response to stress. Or in the sense of relative stress, carefully defined typical stress as the function of the applied load. The thing most significant to us is that in much of the very extensive work done in this area over many millions of miles in truck tire development, there is a very strong correlation statistically, that is, that the uniformity of the stress lines correspond to the performance of the tire in the field. When there is high uniformity there is very high performance, and when there is poor unit structural uniformity from the holographic point of view, there is very poor performance and greatly increased probability of failure in the field. In many cases we wave our hands a lot and say it looks like a Michelin tire and the quality is there and it looks like the fringes have been painted in by Rembrandt, the tire's going to run, run, run, and it will give significantly greater mileage than the tire that looks like it came out of the town dump.

As you go into relative strength, the theoretical considerations comprise an extraordinarily complex field. We on our part are largely tire engineers who are trying to avoid the great cost of allowing rigor to develop into rigor mortis and still keep track of the realities of engineering and physics, as well as the realities of the importance and urgency in doing what we're doing. So much of

it now is the observed data suddenly being reduced in some cases to mileage. But there is a strong correlation between the observed data and the road mileage. Over the last two years there was probably somewhere between 30 to 50 million truck miles; truck tire miles, that have been run under the direct continuous observation of men testing in the field. In the aircraft area we are finding more difficulties with much simulating done; there are a couple of cases with trucks. It is much easier to analyze the truck data than it is the aircraft data, and passenger data is extremely more complex than aircraft data.

Mr. Merhib: I want to thank you very much.

Mr. Vogel: That is the end of the working group session, and if there are no other comments from the floor the meeting is adjourned.

APPENDIX A - BIOGRAPHIES

CHICK, EDWARD E., LTC, is Commander/Deputy Director of the Army Materials and Mechanics Research Center, Watertown, Mass. He has a BS and MS in Metallurgical Engineering from Lehigh University, is a graduate of the US Army Command & General Staff College and various career and specialist courses of the Army Ordnance School and the Army Artillery & Missile School. His 19 years of military experience has been divided between R&D and tactical assignments. He began his active duty at AMMRC in the Metals Research Division; served three years in the Office of the Chief of Research & Development at the Pentagon; and commanded both Artillery and Ordnance units in Vietnam and Korea. He came to AMMRC from duty as the Chief, Materials Branch of the Army's European Research Office, London.

EMERSON, BRIAN, was graduated from Tri-State University in 1971 with a BS in Electrical Engineering. He has been employed at the US Army Tank-Automotive Command since 1972 during which time he received an MA in Management from Webster College. While employed at TACOM, Mr. Emerson has been involved in a wide variety of projects including several which are related to Nondestructive Testing of Tank-Automotive materiel.

GAMACHE, DAVID L., is a graduate of Wayne State University, Detroit, with a BS in Mechanical Engineering. Prior to joining Government service, he worked for nine years for Chrysler Corporation in the development of automotive suspension components. He has been with the Tank-Automotive Command for the past eleven years in the Product Assurance Directorate in the area of quality assurance research. Currently he is Chief, Quality Assurance Division, a part of the new Tank-Automotive Research & Development Command.

GILKEY, JAMES C., received his BS in Mechanical Engineering at Tennessee Technological University, Cookeville, and is currently performing graduate study in Administration of Science and Technology at George Washington University. Since leaving Tennessee, he has been military project engineer at Aberdeen Proving Ground; project engineer in the automotive division of the Office of Research & Engineering of the US Post Office Department; from 1967 to 1971 he served as Supervisory Safety Standards Engineer, Office of Crashworthiness, of the National Highway Traffic Safety Administration (NHTSA), in Washington; and since 1971 he has served as Supervisor, Equipment Group, Office of Standards Enforcement of NHTSA. He is a Registered Professional Engineer.

GRANT, RALPH M., Ph.D., is founder and President of Industrial Holographics, Inc., Auburn Heights, Michigan. He is recognized as a pioneer in the holographic NDT process and the inventor of most applications to NDT of tires by holography. In 1966 he founded GC Optronics, Inc., Ann Arbor, serving as President and Technical Director, and under his guidance GCO became the first independent organization totally engaged in the field of holography (1966-1972). Dr. Grant received his BS in Engineering Mathematics in 1959 at the University of Michigan where he also received his MS degree in Nuclear Engineering in 1961. In 1964 he received his Ph.D. in Physics at the Technical University of the Netherlands, Delft. In 1969, his achievements in conceiving and perfecting applications of holography resulted in his receiving the "Achievement Award" of the American Society for Nondestructive Testing.

HUBINSKY, JOSEPH, was born in Youngstown, Ohio, where he was graduated from the hometown university, Youngstown State, in 1972 with a BE in Mechanical Engineering. He began work with the Government in the same year as an intern in the Quality & Reliability Intern Program. After six months of classroom training at AMETA, Rock Island, Illinois, he was assigned to TACOM, Warren, Michigan, where he completed his intern training. He currently works in the M-113 (Armored Personnel Carrier) Systems Management Office at the Tank-Automotive Research & Development Command.

JOHNSON, RICHARD N., Ph.D., is a Senior Engineer, NDT and Diagnostics Group, GARD, Inc./GATX, Niles, Illinois. He received a BS in Applied Mathematics from the University of Wisconsin-Madison, an MS in Engineering Mechanics from Case-Western Reserve, and a Ph.D. in Engineering Mechanics from the University of Wisconsin-Madison in 1972. He was employed at NASA-Lewis Research Center for six years as a Project Manager in fracture mechanics and materials science research. He has been at GARD for three years involved in materials property research and the development of a numerical street analysis for three-dimensional problems. He was the project manager of the TACOM-sponsored program on tire retreadability and will be the PM on the follow-up research.

KLAASEN, LARRY, was graduated from the University of California, Berkeley, with a BS in Chemistry and he went on to San Diego State University where he obtained his MS in Chemistry. Mr. Klaasen then joined Shell Chemical Company in the field of high polymer aerospace adhesives. He is currently working as a Materials Engineer at the US Naval Air Rework Facility, North Island, San Diego, California. North Island is the cognizant field activity on Navy aircraft tires and is responsible for maintenance engineering and rebuilt tire procurement.

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LICHODZIEJEWSKI, W., is Manager, Electronics Systems, of GARD, Inc./GATX in Niles, Illinois, where he has as principal duties the managerial, technical, and sales responsibilities for a group of engineers and scientists working in electronics and diagnostics. He has a BS in Engineering Physics from the University of Illinois in 1963, and an MS in Physics, DePaul University, 1966. In addition to advanced development in NDT technology, his group works in electro-optics, mechanical reliability, and diagnostics, and they provide services on a task basis to generate test specifications and requirements. Earlier, when with Bell & Howell, Mr. Lichodziejewski worked on advanced development of optical systems such as the application of light-emitting diodes to photographic film systems.

McCONNELL, GWYNN K., serves as a Nondestructive Inspection Specialist, Air Vehicle Technology Department, Naval Air Development Center, Warminster, Pennsylvania. He is responsible for the development and application of nondestructive inspection methods for military aircraft. He is a graduate of Temple University with an Associate Degree in Electronics and he has had over 20 years of experience in various areas of research and development. Mr. McConnell is the author of several papers in his field, and the numerous references in the literature to his work in both pulse-echo and through-transmission ultrasonic testing of tires establish him as a highly innovative pioneer in this complex area.

MERHIB, CHARLES P., has served with the Army Materials and Mechanics Research Center for over 16 years, first in ultrasonic research and more recently as Chief, Nondestructive Testing Information Analysis Center Earlier he was with the US Army Natick Laboratories as a physicist in the Physical Testing Laboratory, and prior to that he worked at the development of infrared night vision devices at the Army's Corps of Engineers R&D Laboratories, Ft. Belvoir, Virginia. He is a 1951 graduate of the University of Massachusetts with a BS in Physics and has continued his studies in universities in the Boston area. Mr. Merhib has two patents and numerous publications to his credit, is serving as the Executive Secretary of the Department of Defense Annual Conference on Nondestructive Testing.

MOORE, G. ROBERT, at the time of the symposium was Chairman of the Akron Rubber Group, Inc., having come up through all the usual offices in the Group to that position of leadership. He started in the rubber industry 26 years ago as a research chemist, went on into technical service work, and then into technical sales with B. F. Goodrich. He joined Harwick Chemical in 1960 to open their Oakland, California office, then returned to Akron in 1965 as District Manager and moved up to Vice President in 1968. Mr. Moore

is a native of Akron, a graduate of Kent State, and a leader in many civic activities involving youth sports and scouting.

NEUHAUS, TED G., at the time of the symposium was Tire Systems Manager for Picker Corporation, Cleveland, Ohio. He has been in the field of industrial and tire X-ray since his graduation from Ohio University, Athens, Ohio, BS, 1956. Mr. Neuhaus has been an active member of ASNT, ASTM, ACS, and ASQC, has chaired many committees, and has presented papers to local and national meetings and educational groups. One of his recent contributions to the rubber industry is a patent for the air-inflated, bead-to-bead inspection, X-ray production system. Subsequent to the symposium, in March 1977, in a merger, he was placed in charge of Sales of Tire Inspection Systems at Monsanto Company, Akron, Ohio.

RYAN, ROBERT PATRICK, Ph.D., received his MS in 1959, and Ph.D. in Physics in 1963 at Brown University, Providence, Rhode Island. His academic and professional background and honors are too extensive to summarize, but some of his achievements include acoustic noise measurements and time-frequency analysis related to acoustic minesweeping, use of seismic techniques for determining sea-bottom structure, study of leaky waveguide effects in underwater sound propagation, radiation field patterns, instrumentation for measurement of degradation of the pulse width of sub-nanosecond laser pulses, studies of optical modulation and detection techniques for high data rate laser communication systems, and others. Dr. Ryan has been with the Transportation Systems Center, Cambridge, Massachusetts, since its conversion from the NASA-Electronics Research Center, where he served as a physicist.

RYDER, JOHN C., is Vice President of Engineering and Manufacturing for Fabricated Machine Company of Massillon, Ohio. He has many years of experience in tire test machinery design as well as tire design, and for seven years he was with Firestone Tire Test Development and Advanced Tire Development. At Fabricated Machine Company, he has managed the tire testing subsidiary, Standards Testing Laboratories, and has been responsible for its manufacturing and engineering functions for the past three years. He holds a MSME degree from Rensselaer Polytechnic Institute and is a Registered Professional Engineer in the state of Ohio.

SCHURING, DIETERICH J., Ph.D., at the time of the symposium was Principal Research Engineer, Vehicle Research Department, Calspan, Corp., where he has been employed since 1968. Prior to that position he was with AC-Electronics Defense Research Laboratories for 5 years, with Battelle Institute, Germany, for four years, and with Organic Terrain Research Institute, Germany,

1952-1959. Dr. Schuring's most recent work concentrated on theoretical and experimental aspects of tires, with particular attention given to wear and traction, mathematical modeling of tire performance, and thermal tire characteristics. His earlier work included analysis of dynamics of lunar vehicles, development of wheels and tracks for cross-country vehicles, and investigations of rheological properties of soil. He is a founder-member of The International Society for Terrain-Vehicle Systems. He is now with Firestone Research Division, Akron, Ohio.

VOGEL, PAUL E. J., a Registered Professional Engineer, serves as a Research Mechanical Engineer at the Army Materials and Mechanics Research Center where he joined the NDT function after graduating from the US Army Command & General Staff College, Fort Leavenworth. He has authored over 30 papers in infrared applications ranging from tire testing to energy conservation and has also published in ultrasonics and acoustical holography. He is active in SPIE, IRIS, the NDT Forum of the Air Transport Association and he holds a number of positions in ASNT including the chair of the Committee on Infrared Techniques for Materials Evaluation, and the ASNT Handbook Coordinator for Infrared & Thermal Testing.

WALKER, RICHARD S., was born in Massachusetts and attended school there before going on to Lehigh University where he earned his BS in Chemical Engineering in 1950. He entered the rubber industry as a chemist with the H.O. Canfield Co. in Bridgeport, Connecticut, and was later transferred to the company's new facility at Clifton Forge, Virginia, as Chief Chemist. Other positions in industry include sales engineer with the Goodyear Chemical Division, supervisor in the development and technical service department of Thiokol Chemical Company, and advertising and promotion manager for the R.T. Vanderbilt Company. Mr. Walker joined RUBBER WORLD first as technical editor and has had increasing responsibilities during his ten-year literary career. Mr. Walker has since joined Rubber & Plastics News as Executive Editor.

WEIR, JAMES D., and WEIR, KAY, the co-authors of the paper herein, have been together as a team in life and in the rubber industry for over 30 years. Jim was operator of a retread plant for ten years, was Director of Testing for International Rubber Industries in Louisville where he developed the glass fiber-belted tire for Owens Corning, and he was President of Retread Technical Corp., Los Angeles, until 1973 when he retired to consult to retreaders and manufacturers and to work more closely with Kay and their son in designing and building machinery for the rubber industry. Mrs. Weir owns and operates the TIRE PRESS, writing and publishing tire articles and books.

APPENDIX B - ATTENDANCE ROSTER

NONDESTRUCTIVE TIRE TESTING SYMPOSIUM

ARMY MATERIALS AND MECHANICS RESEARCH CENTER
SUPPORTED BY THE
AMERICAN ORDNANCE ASSOCIATION

27-29 January 1976

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CONFERENCE SCENES
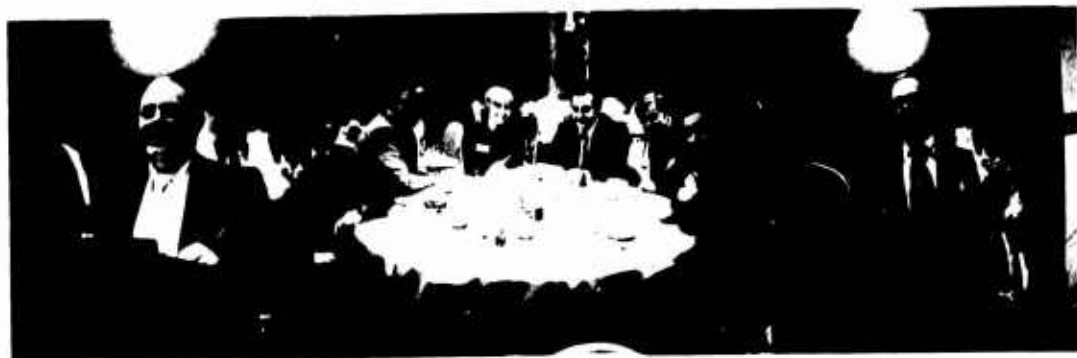
(Left to right) (top row) Mr. Walker; banquet scene; Dr. Johnson; (middle row)
Mr. Emerson; Welcome to Akron; Mr. Gamache; (bottom row) Mr. Hubinsky; Aircraft
Tire Committee Meeting; Dr. Grant.

(Left to right) (top row) Meeting scene; Dr. Ryan; Banquet scene with Mr. Jannarelli and Mr. Lewis; (middle row) Mr. Gilkey; LTC Chick; Mr. Merhib; (bottom row) Mr. Vogel; Mr. McConnell; the Working Group panel.

(Left to right) (top row) Banquet scene; Mr. Gilkey and LTC Chick; Panel
members; (middle row) Mr. Jannarelli and Mr. Gilkey; Cathy O'Keefe and
Mary Ann Beradi from AMMRC; Panel members; (bottom row) Panel members; view
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(Left to right) (top row) Mr. Moore; attendees from AMMRC at banquet; Mr. Lichodziejewski; (middle row) Mr. Weir; Working Group Panel; Mr. Ryder; (bottom row) Dr. Schuring; a meeting scene; Mr. Klaasen.

PROCEEDINGS OF THE FOURTH SYMPOSIUM ON NONDESTRUCTIVE TESTING OF TIRES

PROCEEDINGS OF THE FOURTH SYMPOSIUM ON
NONDESTRUCTIVE TESTING OF TIRES

Dedicated to

Paul E. J. Vogel

Mechanics and Engineering Laboratory
Army Materials and Mechanics Research Center

23-25 May 1978

The Executive Hotel, Buffalo, N. Y.

Sponsored by

Army Materials and Mechanics Research Center
Watertown, Massachusetts 02172

Approved for public release; distribution unlimited.

DEDICATION

This proceedings, the last in a series of four, is dedicated to Paul E. J. Vogel, Chairman of all four symposia, who retired from the Army Materials and Mechanics Research Center in January 1979. Paul was the originator of these symposia which were successful mainly due to his untiring efforts in their behalf.

We at AMMRC wish Paul all happiness on his ranch in Florida, and wish him success in his future business endeavors.

PREFACE

This symposium was designed for the exchange of nondestructive tire testing technology. It was especially aimed at the identification of needs and opportunities in the field and the development of recommendations for the DoD Tire Testing Technology programs and to some extent the needs were identified. Possibly the foremost of these is the need to perform a thorough survey of the state-of-the-art so that DoD testing technology programs can best be related to existing techniques or to practical techniques that need further development. It is hoped that the dialogue that was enjoyed throughout the four symposia will continue by correspondence and visits by all interested elements of the field.

A symposium such as this one could not have been successfully held without the cooperative hard work of a number of people. Thanks are due to many: To Paul Vogel and his committee: D. Gamache, TARADCOM, G. McConnell, NADC, R. Yeager, Goodyear Tire, Jack Price, Air Treads, and C. Merhib, AMMRC; to Kathy Seege of the Executive Hotel for her fine personal efforts expended to assure arrangements were the best available; to personnel of Calspan for the tour provided; to F. James Henry, Buffalo District, U. S. Army Corps of Engineers, for the fascinating dinner talk on the "Dewatering of the American Falls" which gave added interest to the town of Niagara Falls following the Symposium, and to Jim Larson representing the Mayor of Buffalo for providing the welcome.

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James H. Larsen, The Charter House Motel

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CHAPTER I

OPENING REMARKS

COL William R. Benoit
Commander, Army Materials and Mechanics
Research Center, Watertown, Mass.

Thank you Mr. Vogel, our Chairman; Mr. Lavery; and attendees of the Fourth Symposium on Nondestructive Testing of Tires. It's a pleasure indeed for me to be here in Buffalo and have an opportunity to give this address.

The Chairman has told you about my military background. I have always been associated with either aircraft or rubber-tire vehicles, with the exception of one organization where I had the only train in the United States Army. In the last command tour that I had, which was a maintenance battalion, we had two transportation truck companies so I know a little bit about the problems with tires; especially retread tires. And as a rated pilot I've flown aircraft with tires that were recapped with 100,000 miles of life not being unusual at all. Of course the rubber was off the ground for most of those miles. Now some of our tires are not really the sort that you would necessarily prefer to trust your life to because you always find that out after the fact. Under Army Regulation 750-36, which is in force now, we are mandated in the army to use 75% of our tires as retreads, 75% of the tires that we get now are retreads. Mr. Vogel, your Chairman, happens to be very prominent in the Reserve and National Guard back in his home state of Massachusetts and he probably wouldn't care to name the unit, but he knows of one unit where they put the re-treaded tires on, drive around the motor pool, and then they take them off and then put new tires on because they don't trust retreads. Some of the units put the re-treads on the rear wheels only because they don't want to put the danger of having the front tires blow out. As you know, our jeeps now have four wheel independent suspension and a rear wheel blow out can be disasterous as well, so I don't know what they do in that case. I don't want to sound like the preacher who chews out the attendees on the evils of non-attendance but I do want to point out one of the more serious problem areas and you who are here are interested in the latest developments in nondestructive testing for assurance of top quality tires. So you are what we would call the good guys, the white hats, and as we know the good guys are imposed upon by everyone and so I'm not going to be an exception I'm going to place an imposition on you here today. I'm here to say that the army needs help and that's the basic purpose of this Sym-

posium. We want you to tell us which of the hundreds of possible irregularities in a tire can be considered to be serious enough to warrant rejection. We want to know which of the serious irregularities can be identified by nondestructive testing techniques. We want to know what hope there is of developing tests that will be meaningful or lowering the costs of tests that are in use: because it's obvious we have a cost problem, otherwise we probably would not take advantage of retreads. We must establish Army goals and then concentrate our efforts on attaining these goals. Now I don't pretend to be a tire expert, I'm just a user of tires, but I do know that you have the combined expertise here in this room to point us in the right direction. Keep one thing in mind throughout your deliberations; we really need your help. We don't have the answer. For that reason we are asking you to assist in forming recommendations and comments on identifying the priority needs in the tire test area and we'll do this through the medium of the working groups, as you know, and a panel discussion that Mr. Merhib will tell you about. A working group chairman will try to package your thoughts at the end of this and express your best thoughts about this. Now one important phase of the working group activities will be the problem area that's been common to all of us and that's the need for a common language in discussing nondestructive testing of tires. Mr. Bob Yeager will chair this particular working group and many of you will remember him from Akron where he expressed concern for a common nomenclature for tire nondestructive testing. I wish to thank Goodyear Tire and Rubber for allowing Mr. Yeager to work with us this year in probing the questions of the need of some standardization of tire testing nomenclature, equipment performance, etc. It's a sensitive question but it is in the hands of a man who has an unusually broad knowledge of tires and suspension problems and who will have in mind the best interest of the entire rubber industry as he leads his group work.

Now back in New England, we have a form of Government known as the Town Meeting in most communities, certainly the one that I grow up in. This allows every citizen to stand up and be heard if he wishes. I'd like to tell a little

story. In one of the meetings, a man stood up and said, "I understand that when little Suzie Jones had her baby the town paid $125 for the delivery." The moderator answered as to how that was correct. And the man continued and said, "and I understand the State reimbursed the town $150 for that delivery." And the moderator agreed that that was the right figure. "Well then," said the speaker, "since this is the first transaction in which the town has shown a profit, I make a motion we breed her again."

We were going to stop these tire symposia after three meetings but they've been so mutually profitable that we've decided to breed her again. That's why we're here today. Between us, I'm sure we can show a profit for the Army and the manufacturers of tires and tire test equipment, and also for the taxpayer who pays for our research and buys tires and retreads.

I look forward with interest to your panel formulation of identifying needs and solutions for DoD tire testing improvement. Thank you very much.

CHAPTER II

KEYNOTE ADDRESS

A. L. Lavery
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It is an honor to be the keynote speaker for the Fourth Symposium on Nondestructive Testing of Tires. This meeting is sponsored by the Army Materials and Mechanics Research Center which is located in Watertown, Mass. The purpose of the meeting is to foster the exchange of nondestructive tire testing technology, to identify needs and opportunities within the field, and to develop recommendations for the DOD tire testing technology program. This program is concerned with new tires, stored tire degradation, and retreaded tires for use on operational ground vehicles, support equipment, and aircraft. Current military regulations call for the utilization of retreaded tires for many of this equipment. The Army Regulations call for a 75% use of retreaded tires. It is in this area that a considerable amount of the current work is centered.

In the first of this series of symposia, Richard D. Meyer, Assistant to the President, Firestone Tire and Rubber Co., was the industrial keynoter. In his address, he characterized the nature of tires and the desirable features of an NDT system to inspect tires. Since I believe that his remarks are still meaningful, I will take the liberty of paraphrasing them. On the characterization of tires, the following were the principal parts.

- A tire designer has approximately 20,000 theoretical options for tire design.

- A tire is an individual assembly of components. When it fails, it must generally be totally replaced.

- Variations in the components and the artisan tire builder produces a product which will differ from the norm. Sampling does not give absolute assurance that each tire in a batch behaves like the sample.

- Use factors, including the operator, affects tire performance by widely measurable degrees.

These brief summary comments imply that this composite we call tires are indeed a complex system. It is this very factor which makes this field of the nondestructive testing of tires so difficult and so challenging.

The principal points he made for an inspection systems' characteristics follows:

- Perceived benefits must be equal to or greater than the cost of inspection.

- The method must be production oriented to inspect 100% of the product.

- It cannot be too delicate and must be easily maintained.

- It must be consistent and produce identical values of identical items and provide these results in an easily interpreted manner.

- It must measure parameters which are verifiable through road or other physical testing.

I believe the above remarks were particularly meaningful since they represented the view of a senior tire company executive concerning a complex engineering problem.

During the course of this symposium, we will hear about the current progress in many areas, including tire mechanics, critical defect size, and nondestructive testing of beads and carcasses by ultrasonic, holographic, x-ray, and other methods. Clearly, many of the methods which will be reported upon will generally meet the previously stated characteristics for a tire inspection system. As engineers, we will recognize the innovative approaches and the engineering difficulties. We will also relate our experience to those reported upon and leave this symposium with a broader knowledge and better understanding of this tire inspection area. But this better technical understanding will not guarantee the success of either the industry or government tire inspection programs. Since very few of us here are the policy makers who approve major buys for this type of equipment; it might be beneficial to look at a few of the factors which are required to make such buys possible.

First, there must be a *need*. The need may be based upon a decision such as decreasing tire adjustments, complying with a 75% retread regulation, screening compliance test tires, or the evaluation of physical testing. As a result of these types of decisions, a need to provide inspection methods (which could be either visual or instrumentation) can be identified. The identification of the specific need bounds the problem. It allows the specific identification

of potential benefits. The benefits can, of course, take many forms. They may relate to the readiness of combat units, the safety of aircraft, or the reduction of tire adjustments. One often includes the cost of litigation, and societal costs as part of the estimation of benefits. Policy decisions are often based in part upon the ratio between the *benefits* and the *cost* of implementing the inspection process to fulfill the need.

Since most solutions to a specific need are not 100% effective, the potential benefits are adjusted to determine effective benefits. This approach provides the general basis for the benefit/cost and return on investment considerations which so many policy decisions consider. From the engineering viewpoint, the cost of implementing a method for inspection and its effectiveness in fulfilling a specific need can be seen to have a definite impact on the decision to deploy a candidate inspection system.

The second problem is to determine which *physical parameters* must be controlled to meet the specific need. Stated another way, what are the failure modes and the precursors of failure, which if they are eliminated, would satisfy the need. This part of the process is perhaps the most difficult and yet the most neglected part of many inspection programs. Those of you who have inspected tires for separations, found them, and then not having them propagate to failure during wheel or road tests, while a separation-free tire failed the same test due to separations, will appreciate the problem. Could it be that in *new* tires the presence of small separations is not necessarily indicative of either poor quality control or potential product failure? If this is so, then perhaps the precursor to tire failure due to the separation mode may be either in the components, the adhesion between components or in allowable design variations. These factors *must* be determined before the design of inspection methods to control this failure mode can be developed. Most of the needs which are addressed by the various tire inspections programs are concerned with several potential tire failure modes. Thus, the requirement exists to identify each failure mode, the probability of failure for each failure mode, and the mechanics of the failure mechanisms. This approach will provide information necessary to properly apportion program resources, and to identify the potential measurables at the point of inspection for controlling the failure mode. It is very important to identify these measurables or latent defects related to the mechanics of failure which would exist at the point of inspection. For example, if one can only identify a latent defect after 1,000 miles of road use, then an inspection system for use at the manufacturing point to control that failure mode would have no utility. In fact, work to develop such a device by consuming valuable resources with a nil probability of controlling the failure

mode would have a very negative impact on the overall success of a program.

The third step in a successful inspection program is the development of suitable *inspection methods*. In this development, the inspection methods must fulfill the requirements as to cost, the detection of those precursors of failure, time of inspection, maintainability, and operation within the physical environment. The cost elements include capital equipment, operators, maintenance, consumable supplies, spaces occupied, and the percentage of product rejected due to false alarms. There is, of course, a relationship between the detection probability and the false alarm rate. Generally, the more subtle the precursor to the failure mode being detected the greater the false alarm rate. The trade-off is always to a lower detection probability to obtain an acceptable false alarm rate. Inspection cost is also directly impacted by the inspection time. The greater the time the greater the cost. The trade-offs between the cost elements and the ability of an NDT system to satisfactorily meet the other requirements represents a difficult engineering challenge. However, this challenge must be met to provide an inspection system capable of successfully meeting the criteria for a stated benefit/cost ratio or a required return on investment. If the criteria cannot be met, then the method is unlikely to be deployed.

During the course of this conference and its workshops, we each have an opportunity to impact the outcome of the several tire inspection programs sponsored by industry and government groups. This positive impact can be in the following area:

- the definition of needs and benefits

- the identification of failure modes, probability of failure for each mode, and the failure mechanics leading to each failure mode

- to continue to develop cost effective inspection system

- and to characterize these systems as to the probability of detection and false alarm rate.

As you know, these are difficult challenges. You, the collective attendees at this meeting represent the principal expertise in tire mechanics and tire inspection technology within this country. I am confident that you will meet this challenge and make the nondestructive testing of tires even more successful in the future than you have in the past. Good luck and thank you!

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CHAPTER III

AIRCRAFT TIRE MECHANICAL PROPERTY TESTING

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Wright-Patterson Air Force Base, Ohio

Tire mechanical properties are forces, moments, and other load reactions exhibited by tires when in contact with a surface. These properties must be measured and specified for aircraft tires in order that landing gear designers and engineers can properly integrate their influence into overall aircraft ground performance and handling. They are also necessary for improving tire manufacturing techniques, processes and materials for optimization of the ground performance of an aircraft tire while maintaining or improving other aspects of tire performance such as wear and cut resistance. The trend of high performance aircraft is toward higher take off speeds with the tires being required to fit in smaller envelopes and be inflated to higher pressures. This trend has contributed toward the problems of aircraft directional control during take off and landing and in a number of incidents involving "veer off" and "runway overshoot", particularly during landing on wet or icy runways and during crosswind situations.

In contrast to automotive tires, the mechanical properties of aircraft tires are largely unknown. This lack of data is a significant deficiency in landing gear design and in the prevention of, or solution to, landing gear problems involving shimmy, steering, traction, and cornering. Tire performance characteristics have an effect upon and interact with the strut, brakes, antiskid and steering systems. To understand these interactions and their effect on the landing gear system, a complete set of aircraft tire mechanical property data must be available.

Unique tire test capabilities exist at the Air Force Flight Dynamics Laboratory (AFFDL) which allows for the accurate measurement of aircraft tire mechanical properties. These properties are compiled with the use of a flat surface tire force machine and a computer controlled, 120 inch dynamometer test system. Both of these test systems support a tire/wheel assembly by a metrical frame containing six load cells through which the loads are applied and the resultant tire forces and moments are reacted.

The data obtained from these test machines provide basic information on how well aircraft tires can be expected to perform their function. The data can also be used to aid landing gear and tire engineers and designers in dealing with tire related problems such as shimmy, wear, ground handling, steering, brake, antiskid performance and vertical energy absorption.

An aircraft tire must support the weight of an aircraft and its contact with the pavement must generate all ground control forces during taxi, take off, and landing. These forces include the fore and aft frictional resistance during braking and the lateral forces necessary for directional control in crosswind operations and in turning. The tire must absorb impact landings, and together with the shock strut dissipate the vertical kinetic energy of the aircraft during landing. The tire must also demonstrate adequate structural fatigue life and long tread life.

The aircraft tire plays a dominant role in the overall performance of the landing gear. The tire mechanical properties have an effect upon and interact with the strut, brakes, antiskid and steering. Tire mechanical properties are known to be primary contributors to "gear walk", shimmy, and truck "pitching", which are various forms of dynamic instability. Other types of interactions also occur; for example, brake application reduces the ability of the tire to provide lateral steering force. This, in turn, can lead to a loss of directional control of the aircraft, particularly on wet runways.

Developing and fabricating aircraft tires can best be categorized as an art rather than a science. Aircraft tire development is accomplished largely by "build and try" methods. Design and manufacture, particularly the rubber compounds used, are highly proprietary to the individual manufacturers. The missing link is the technical capability of measuring, correlating, and specifying the performance characteristics of tires, in addition to structural integrity and wear. The AFFDL flat surface tire force machine and the 120 inch programmable dynamometer provide the means to fill this technology gap.

FLAT SURFACE TIRE FORCE MACHINE

The AFFDL/FEM flat surface tire force machine is the first indoor laboratory machine designed for the measurement of aircraft tire properties under aircraft loads with combined steering, camber and braking on flat pavements (see Fig. 1). It accommodates tires in a size range between 16 inches and 56 inches outside diameter, with vertical loadings up to 80,000 lbs., and is instrumented to measure all six force and moment components developed by the tires. The machine is designed to permit low speed tests at slip (yaw) angles between ± 90 degrees
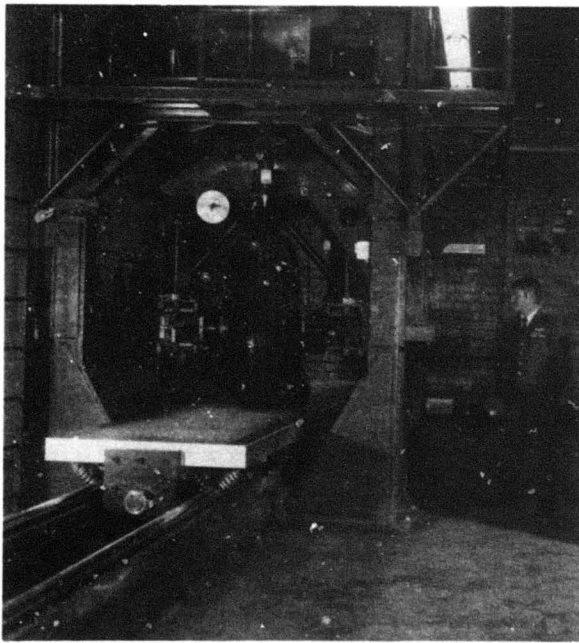
FIGURE 1
FLAT SURFACE TIRE FORCE MACHINE

the $\pm$90 degree position is used for lateral stiffness tests), camber angles between $\pm$20 degrees, and any desired value of longitudinal slip. The force measuring system consists of a series of six Model 1220 Interface Load Cells. Automatic data logging on analog magnetic tape recording equipment provide for accurate recording of data for rapid processing. The data acquisition and data processing flow chart is shown in Fig. 2. The moveable table is constructed such that the normal test surface may be replaced with slabs of various paving materials such as concrete and asphalt. In addition, soil trays may be added for flotation studies.
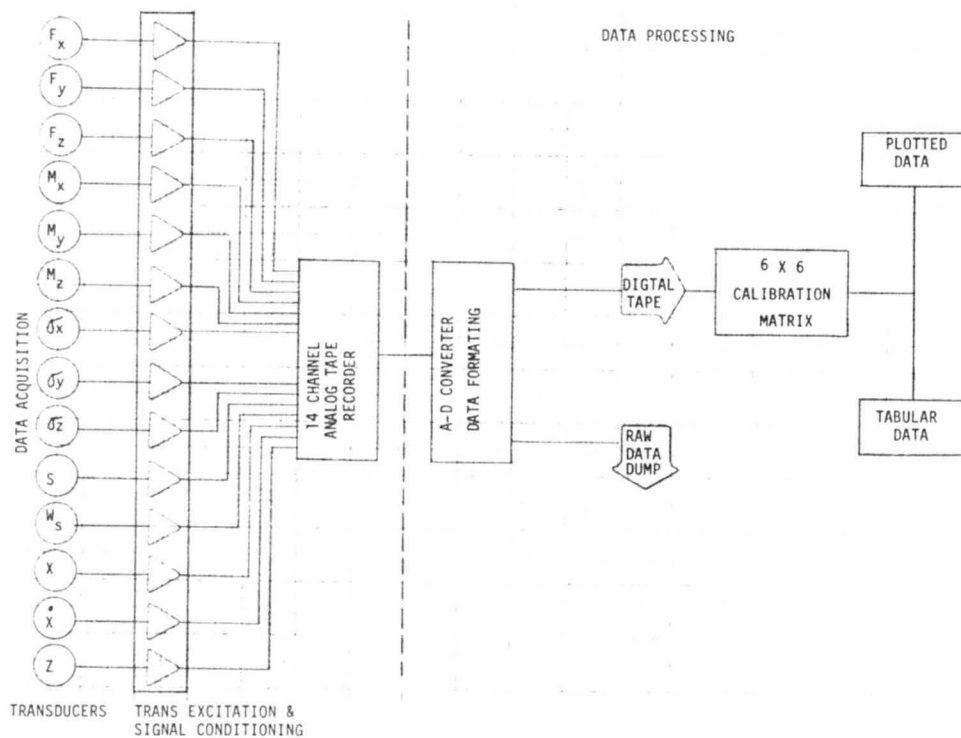
FIGURE 2

TIRE FORCE MACHINE DATA ACQUISITION AND PROCESSING

6

The specifications and testing capabilities of the flat surface tire force machine are shown in Table I.

Table I

Tire Force Machine Specifications

Velocity	0.25 ft/sec – Constant Speed
Total Length	20 ft.
Useable Length	18 ft.
Drive	7 in. Diameter Hydraulic Cylinder

Tire Test Capability

Max. Tire Size	56 x 16 – 56 in. Outside Diameter
Min. Tire Size	6.00 x 6 – 17 in. Outside Diameter
Max. Vertical Load	80,000 lbs.
Max. Camber Angle	±20 Degrees (2 Deg Increments)
Max. Slip Angle	±90 Degrees (Infinitely Variable)
Max. Tire Velocity	0.25 ft/sec
Max. Brake Torque	50,000 ft-lbs

Data Recording

Signal Filtering	3 HZ – Low Pass
Test Monitor	8 Channel Strip Chart Recorder
Data Sampling Rate	Variable
Tape Unit	14 Channel Bell & Howell Data Tape VR-3700B

Data Processing

Data General Corp. Nova 2/10 Digital Computer

Output Parameters

Lateral Force, F_y
Normal Force, F_z
Tractive Force, F_x
Rolling Resistance Moment, M_y
Overturning Moment, M_x
Self Aligning Moment, M_z
Effective Rolling Radius, R_e
Percent Slip, s
Table Position, x
Normal Contact Pressure, σ_z
In-Plane Footprint Shear Stress, σ_x, σ_y
Wheel Angular Position, θ

Mechanical property data, which is a function of one or more of the output parameters, consists of such items as load vs. deflection data, tractive force vs. tire slip ratio, obstacle engulfment properties, footprint areas, tire contact pressure distribution, lateral force and self-aligning torque. All data compiled on both the tire force machine and 120 inch programmable dynamometer conforms to the SAE tire axis system. The rolling tire forces and moments according to the SAE tire axis system is shown in Fig. 3.
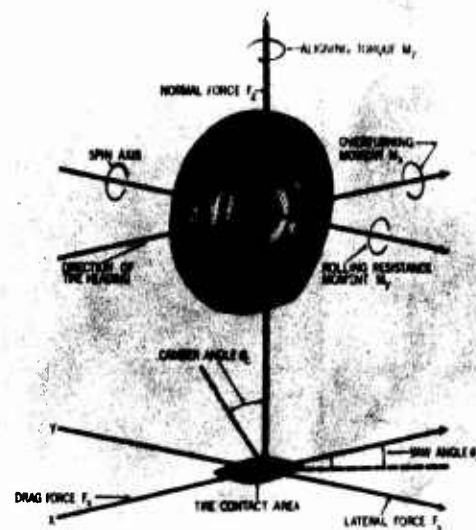
ROLLING TIRE FORCES AND MOMENTS

FIGURE 3

Load vs. deflection tests are performed in three directions, namely vertical, lateral and fore-aft. Tire spring rates and hysteresis are calculated for all three modes of deflection. In addition, the effective coefficient of friction, the vertical sink and the center of pressure shift are calculated for the lateral and fore-aft load vs. deflection tests. Figures 4, 5, and 6 are typical load vs. deflection plots from the flat surface tire force machine.

Footprint net and gross areas and footprint pressure distribution curves are obtained at various vertical loads and tire inflation pressures. The footprint pressure distribution is obtained via an xyz triaxial sensor developed by Photolastic Inc. (see Fig. 7). This device measures two in-plane shear stresses and the normal stress in the tire contact area. Figures 8, 9, and 10 show, respectively, tire in-plane shear parallel to tire rotation, tire in-plane shear perpendicular to tire rotation, and tire stress normal to the table surface.

Tractive force vs. tire slip ratio is obtained by use of an electro hydraulic control system which modulates the brake pressure to obtain a prescribed amount of circumferential slip. This data is obtained as a function of tire load, inflation pressure and tire steer angle. A plot of tractive force vs. tire slip ratio is shown in Fig. 11.

Obstacle engulfment properties are obtained by rolling the tire over various simulated "potholes" and obstructions that can be placed on the tire force machine table. The tire inflation pressure and vertical load is varied when conducting a sensitivity analysis of the vertical reaction
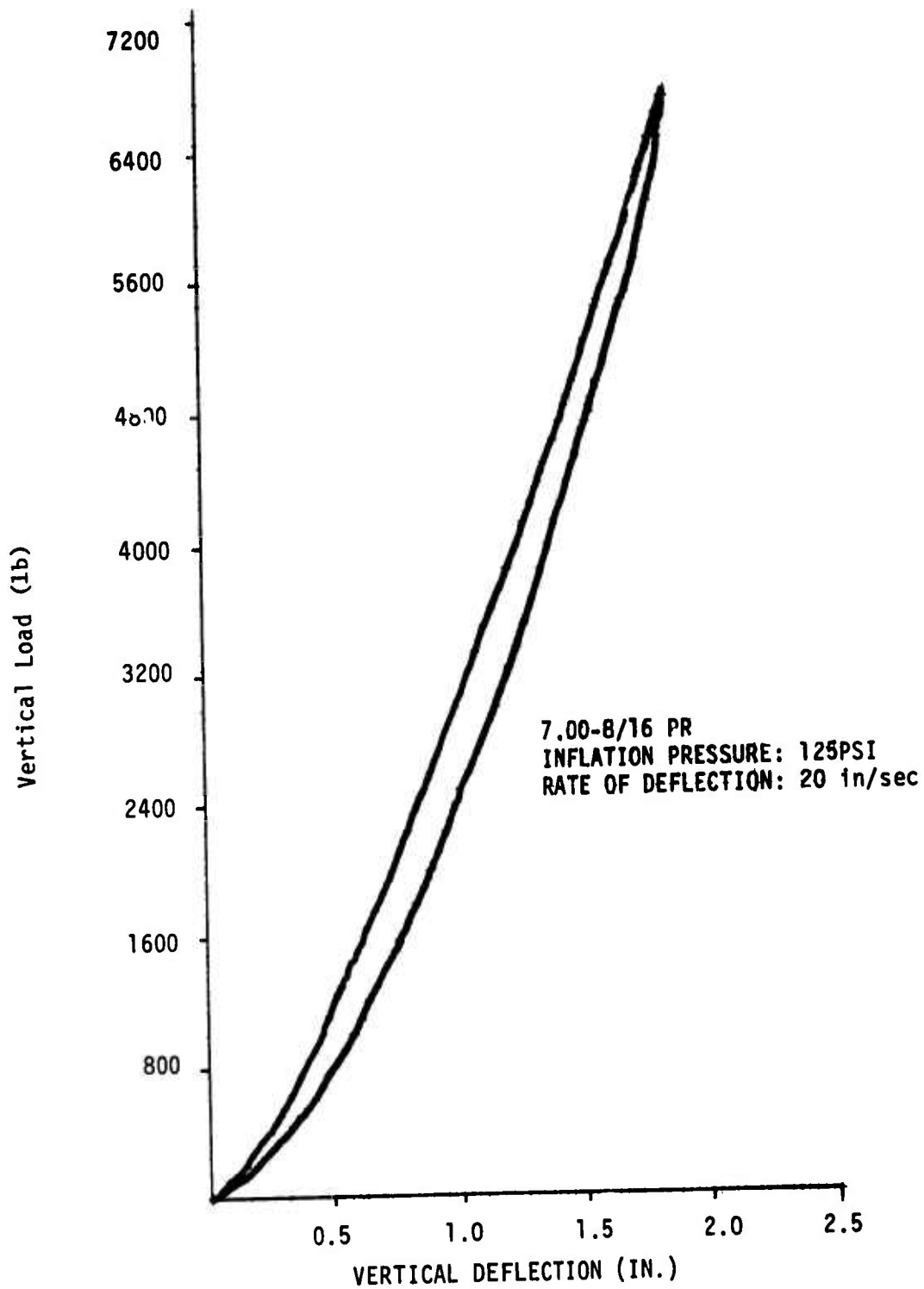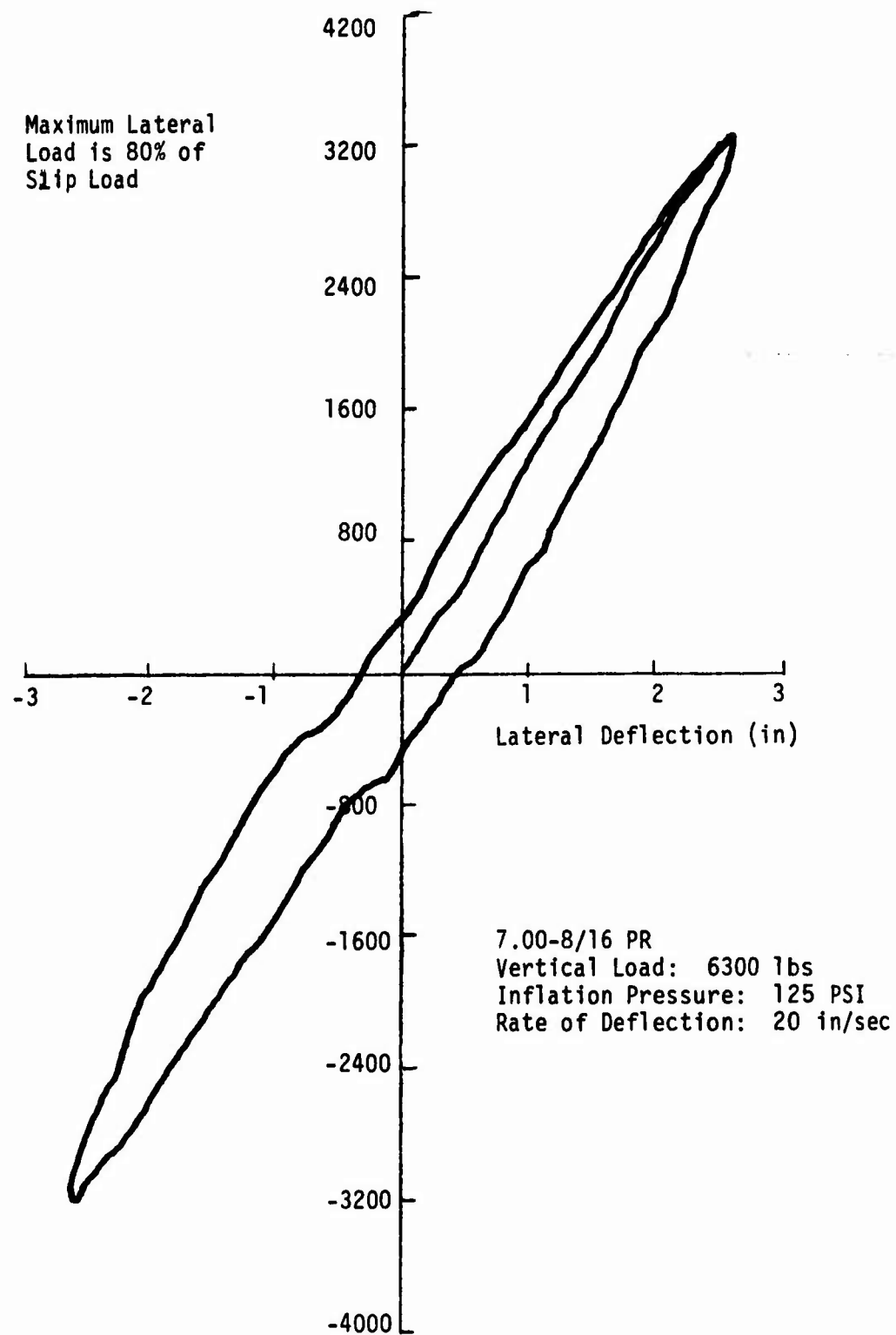
7

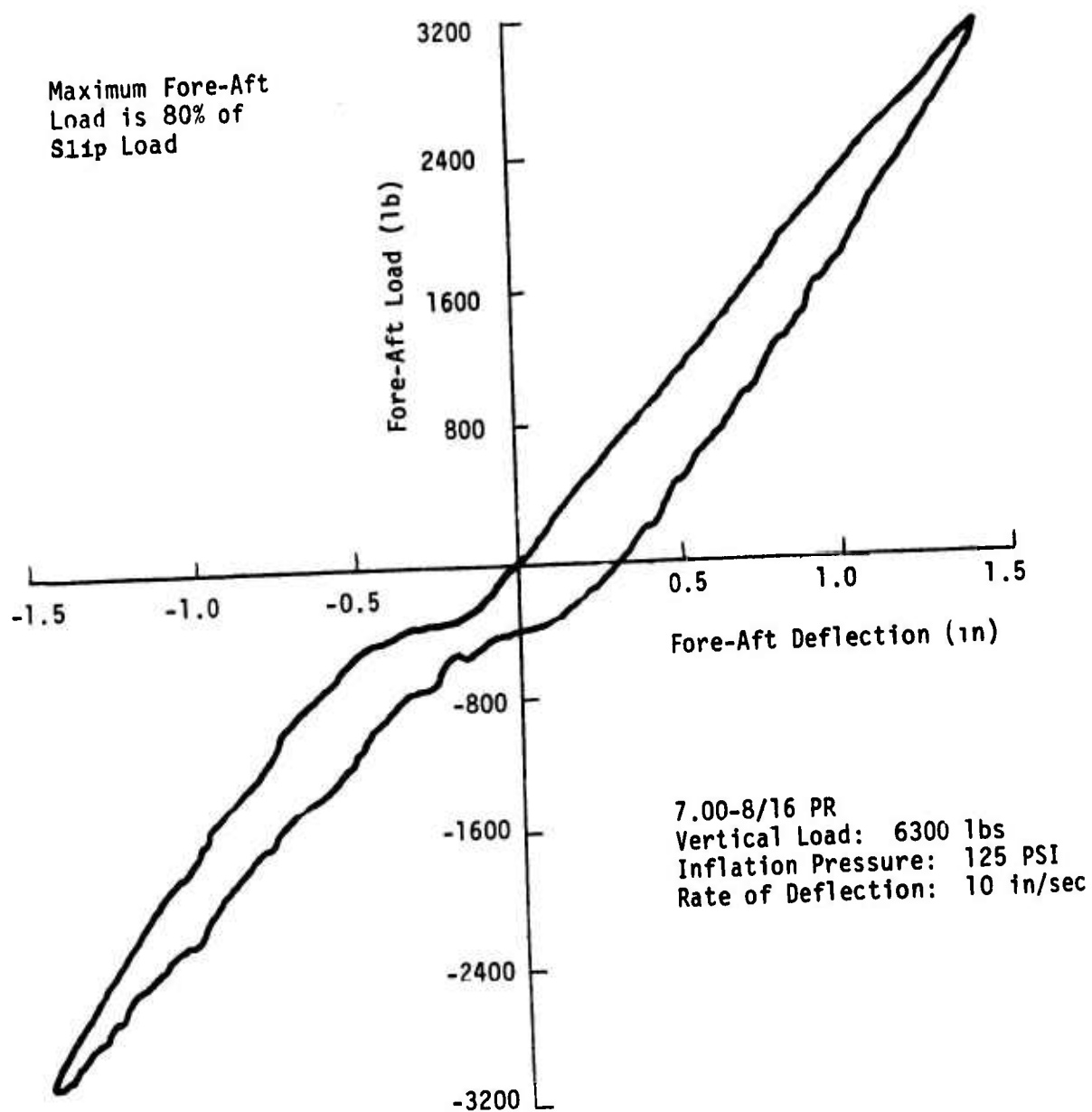FIGURE 4 VERTICAL LOAD VS VERTICAL DEFLECTION

8

Maximum Lateral
Load is 80% of
Slip Load

7.00-8/16 PR
Vertical Load: 6300 lbs
Inflation Pressure: 125 PSI
Rate of Deflection: 20 in/sec

FIGURE 5 LATERAL LOAD VS LATERAL DEFLECTION

9

FIGURE 6   FORE-AFT LOAD VS FORE-AFT DEFLECTION

10
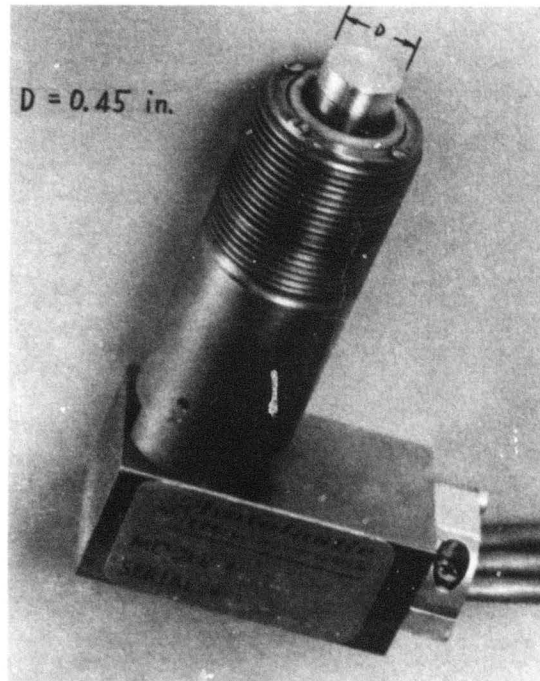
FIGURE 7   XYZ Triaxial Stress Transducer

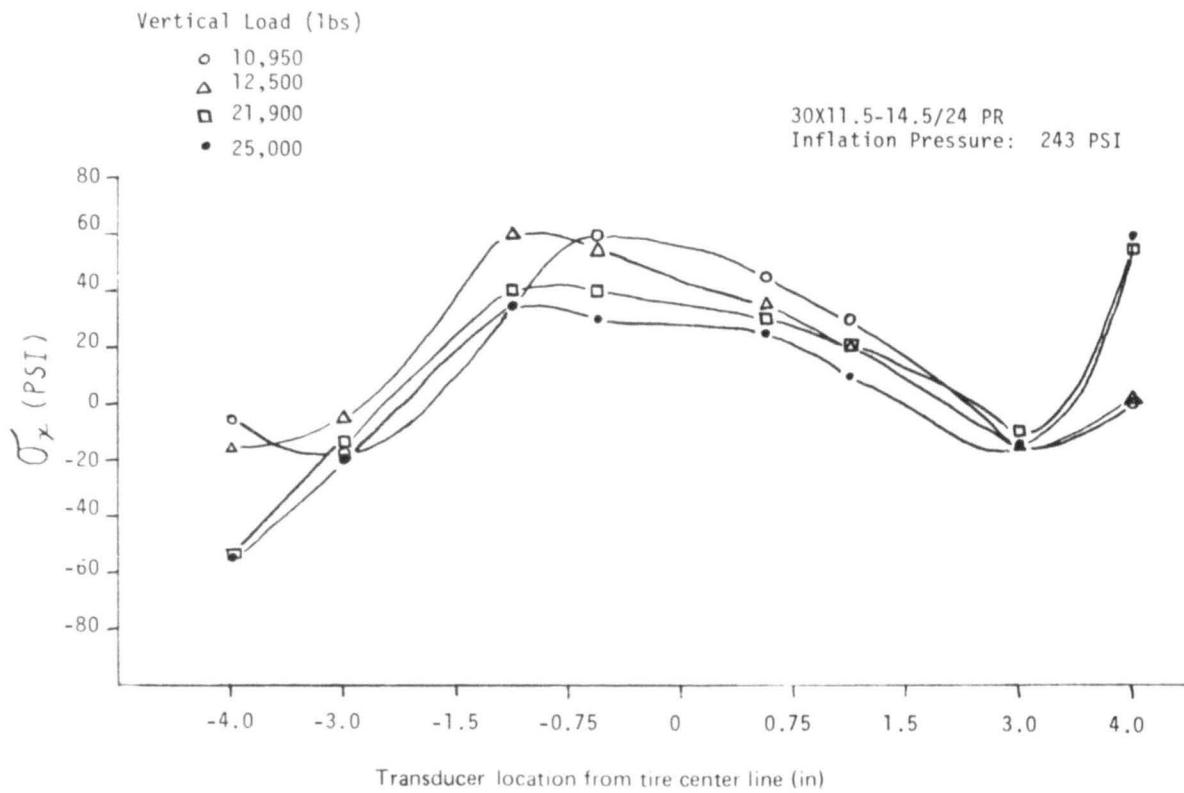Vertical Load (lbs)

○ 10,950
△ 12,500
□ 21,900
● 25,000

30X11.5-14.5/24 PR
Inflation Pressure: 243 PSI

Transducer location from tire center line (in)

FIGURE 8   TIRE IN-PLANE SHEAR STRESS—PARALLEL TO TIRE ROTATION

11

Vertical Load (lbs)

○ 10,950
△ 12,500
□ 21,900
• 25,000

30X11.5-14.5/24 PR
Inflation Pressure: 243 PSI

σ_y (PSI)

Transducer Location from Tire Center Line (in)
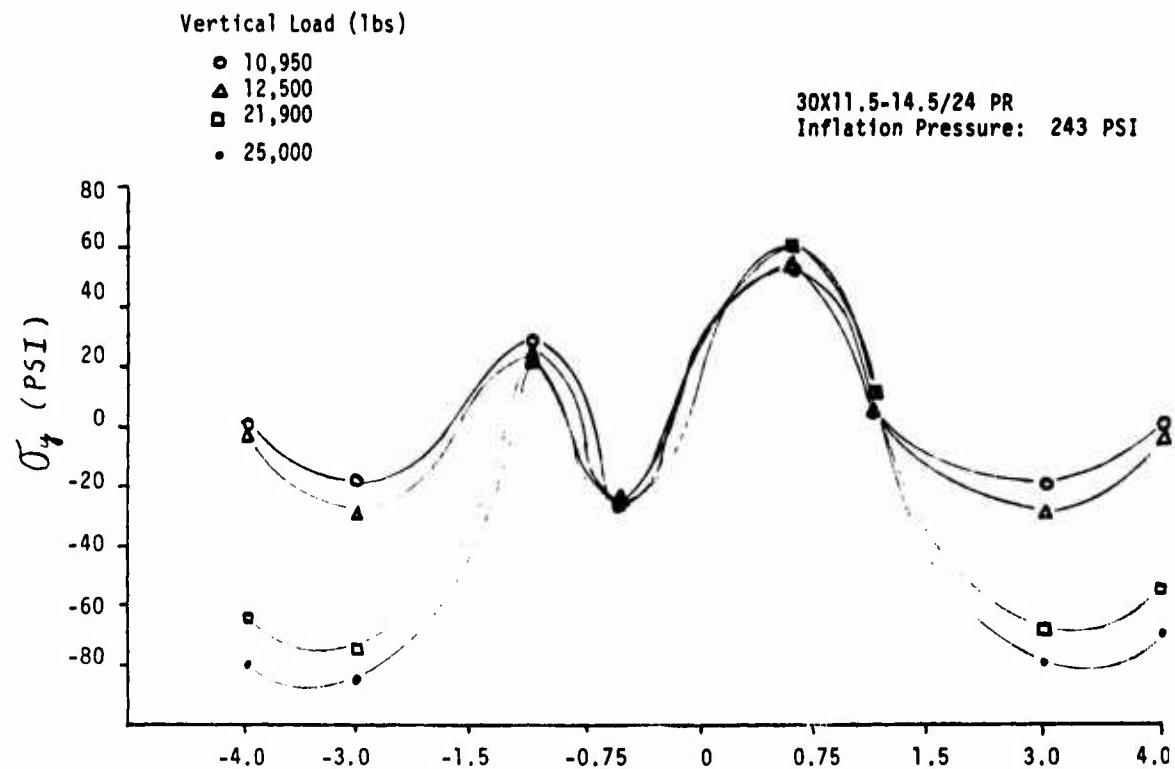
FIGURE 9 TIRE IN-PLANE SHEAR STRESS—PERPENDICULAR TO TIRE ROTATION

Vertical Load (lbs)

○ 10,950
△ 12,500
□ 21,900
• 25,000

30X11.5-14.5/24 PR
Inflation Pressure: 243 PSI

σ_z (PSI)

Transducer Location from Time Center Line (in)
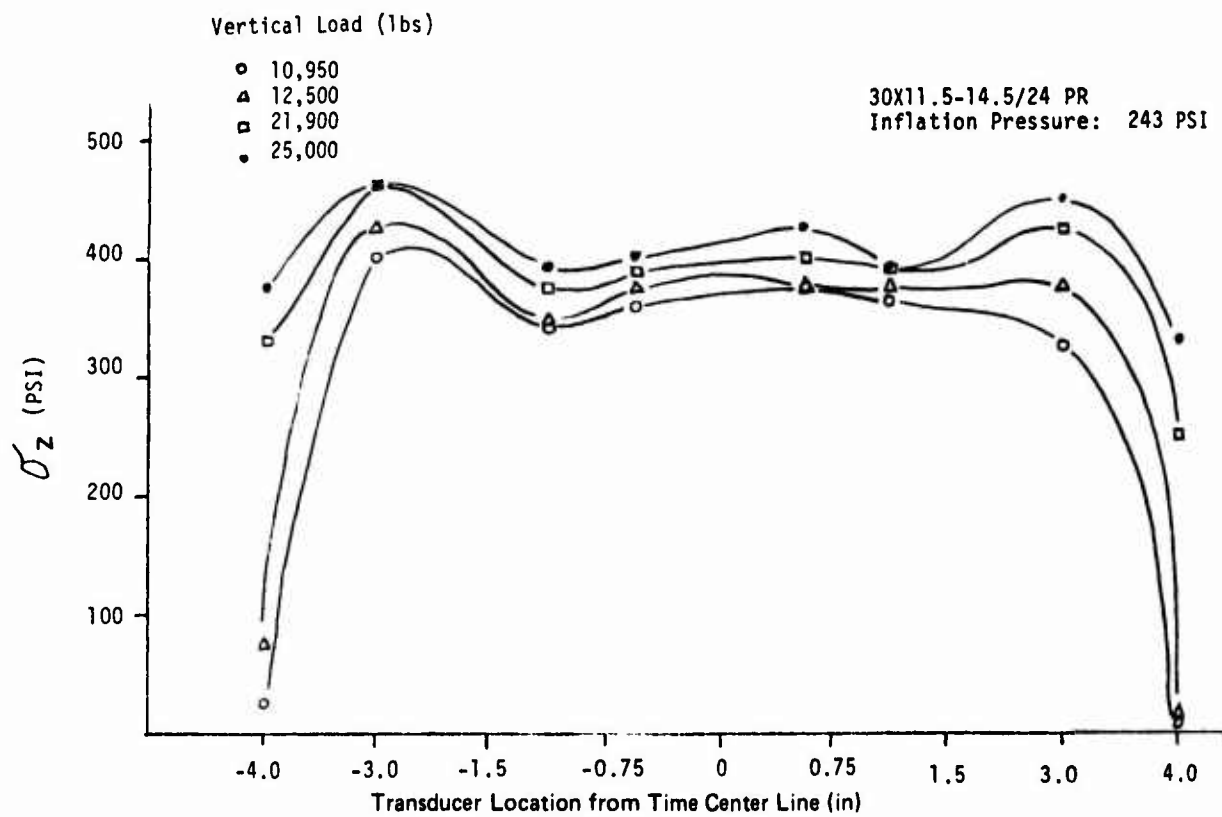
FIGURE 10 TIRE NORMAL STRESS

12
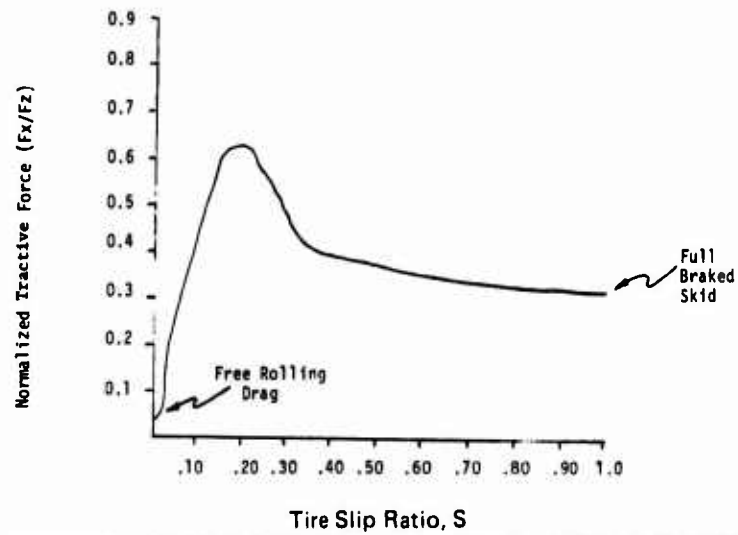
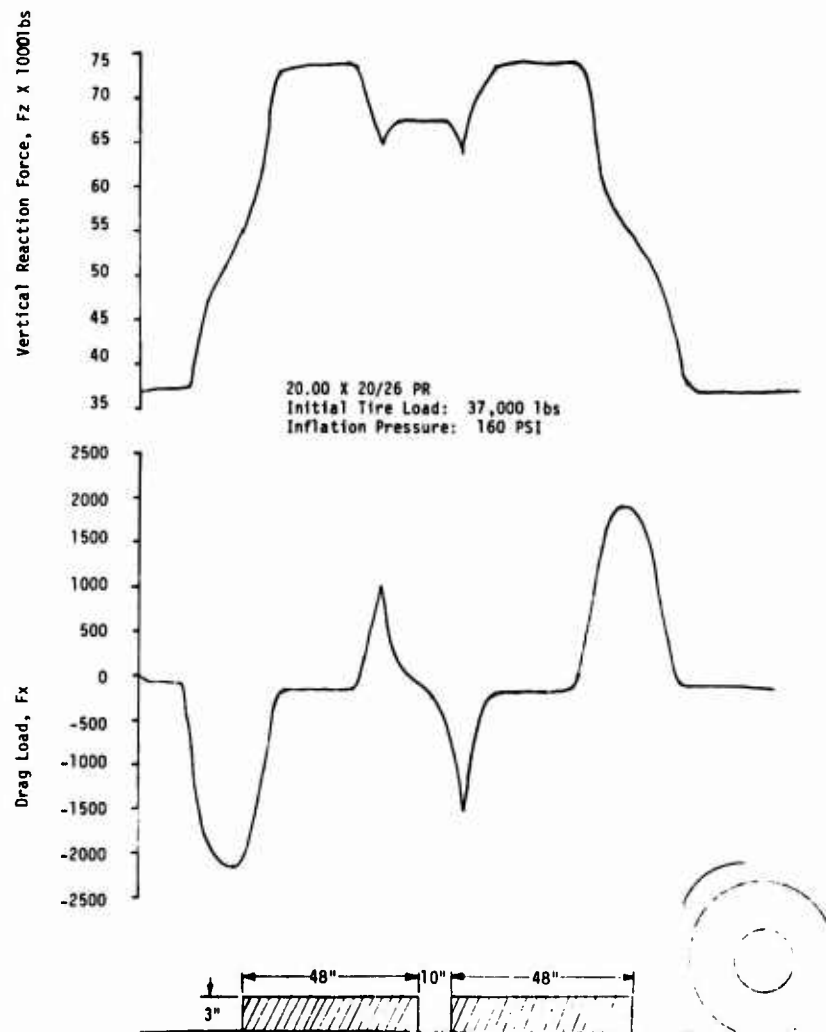FIGURE 11   NORMALIZED TRACTIVE FORCE VS TIRE SLIP RATIO

FIGURE 12   REACTION FORCES DURING OBSTACLE ENGULFMENT TESTS

13

force and the drag force acting on the tire assembly as the tire rolls over the simulated obstacles. Fig. 12 shows the vertical reaction and drag force developed during an obstacle engulfment test of a 56 inch outside diameter tire rolling over a 3 inch obstacle with a 3 inch deep, 10 inch wide "pothole".

Lateral force and self-aligning torque are two of the more important tire mechanical properties. They play a major role in providing vehicle directional control and dynamic stability of landing gear. These two mechanical properties are studied at various values of tire vertical load, tire inflation pressure, tire slip angle, tire forward velocity, and carcass and/or contained air temperature. The influence of surface pavement and surface contamination on these properties are also measured. Typical lateral force carpet plots and self-aligning torque carpet plots as a function of tire vertical load and tire slip angle are shown in Fig. 13 and Fig. 14, respectively.

Various other tests are conducted on the flat surface tire force machine. One of these involves measuring the normal stress at the tire tread and carcass interface when operating on flat and curved surfaces. The normal stress is measured by embedding stress transducers under the tire tread during a retreading process. Typical tire stress transducers and a cross section of a small aircraft tire are shown in Fig. 15. Rolling simulation on various curved surfaces is accomplished by rolling tires over arcs constructed of hardwood and clamped to the tire force machine surface. Conducting all curved surface stress measurements on the tire force machine eliminates the need to transport the tire/wheel assembly to the various dynamometers. It also eliminates the variation of the various load and load measuring systems. Fig. 16 shows an instrumented tire mounted on the tire force machine and rolling on a simulated 84 inch diameter dynamometer during stress measurement recordings.

Data from these tests indicates that the normal stress increases on surfaces with smaller radii of curvature. The standard procedure to compensate for dynamometer flywheel curvature is to increase the tire inflation pressure. This is done to duplicate flat surface tire deflection. However, analysis of this data indicates that this method is incorrect and that tires are being "over tested". This appears to be true, in that tread separation failures occur
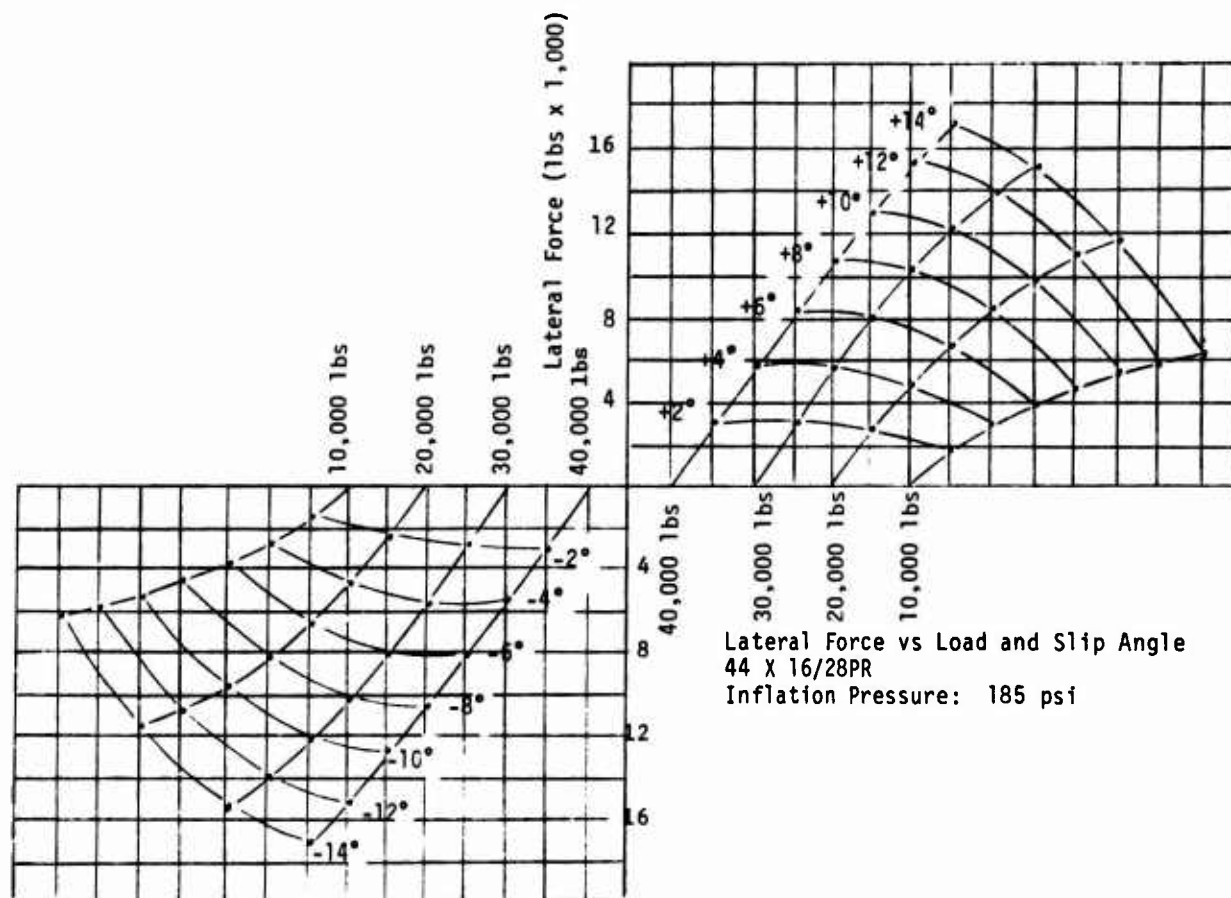

Lateral Force vs Load and Slip Angle
44 X 16/28PR
Inflation Pressure: 185 psi

FIGURE 13 AIRCRAFT TIRE LATERAL FORCE CARPET PLOT

14

Self-Aligning Torque vs Load and Slip Angle
44 X 16/28 PR
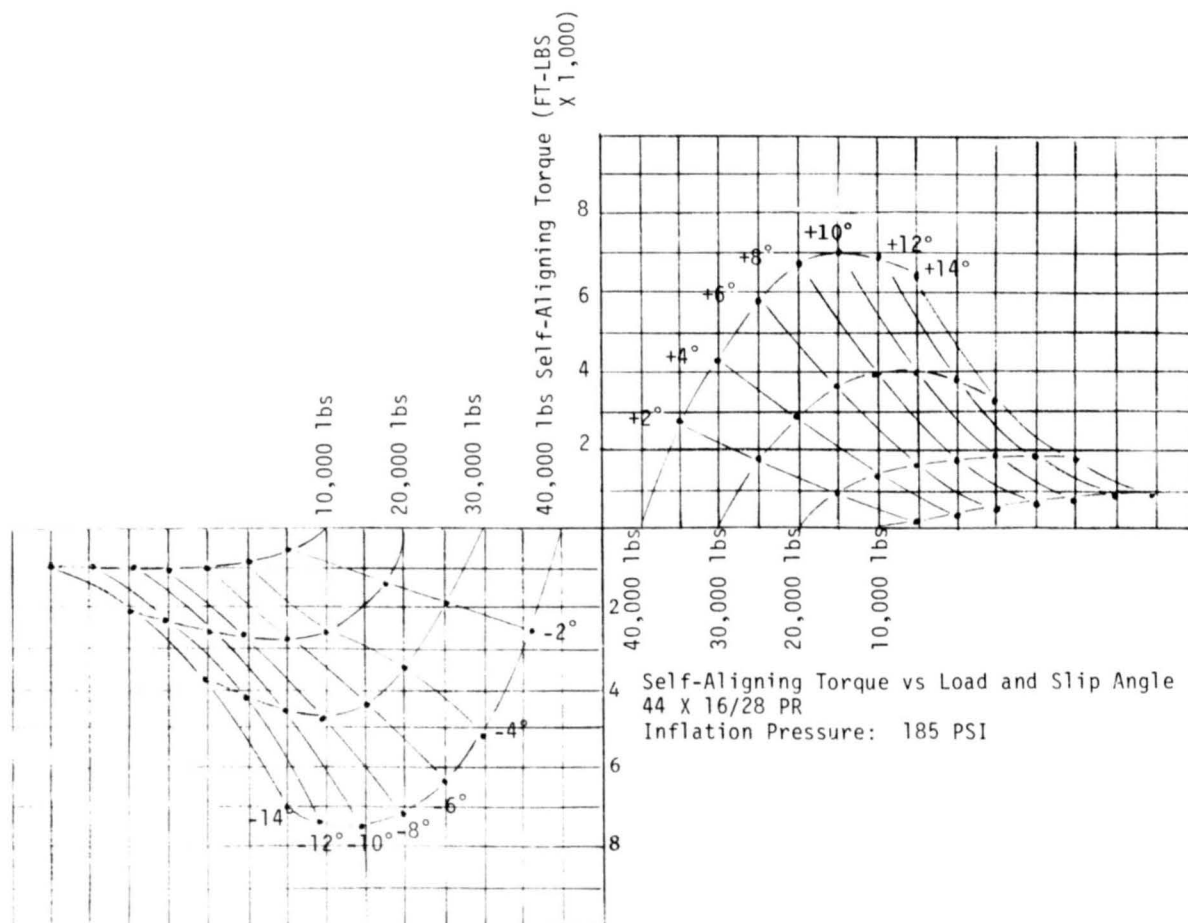**Inflation Pressure: 185 PSI**

FIGURE 14   AIRCRAFT TIRE SELF-ALIGNING TORQUE CARPET PLOT

frequently in the laboratory whereas replacement of a tire in the field before tread wear out is generally due to cuts and tears in the tread and shoulder region. A stress carpet plot for a small aircraft tire is shown in Fig. 17, which indicates that duplication of the normal stress experienced by a tire operating on a flat surface is achieved by reducing the vertical load on tire.

Various other load and/or deflection correction methods are being investigated. All correction methods are then tested by subjecting new tires with full skid depth and new tires with the tread buffed to a minimum skid depth to taxi take off tests until failure occurs. Tires with full and minimum skid depth are tested to ascertain the influence of tread thickness in new tire qualification tests. Tires tested per a certain curvature adjustment procedure are taken from the same production lot and then screened by holographic NDI to establish a quality control acceptance criteria. Based upon the dynamometer test results, a relationship between tire stress levels and dynamometer diameter for various sizes and types of aircraft tires will be
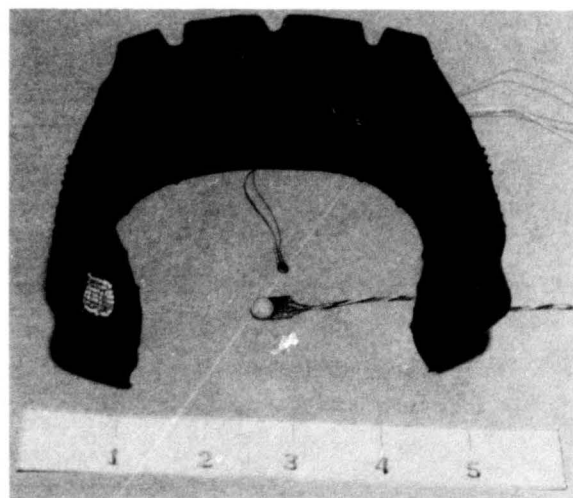

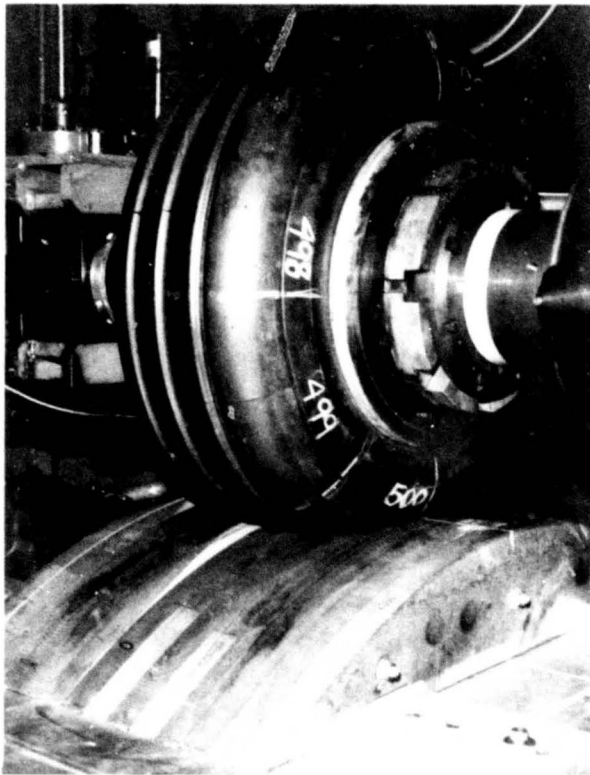FIGURE 15   SMALL AIRCRAFT TIRE
AND STRESS TRANSDUCERS

15

FIGURE 16 MEASURING STRESS
NORMAL TO TIRE TREAD AND CARCASS

established. Ultimately, a change in the military tire qualification specification will be recommended with emphasis on the procedure to evaluate tread retention, to compensate for dynamometer flywheel curvature, and on the number of tires required to meet the qualification specifications.

120 INCH PROGRAMMABLE DYNAMOMETER

The advanced, programmable dynamometer incorporates a six component force measuring system similar to the tire force machine with six load cells arranged in a rigid structure containing the tire/wheel assembly and attached to the primary carriage by flexure struts. This dynamometer has the capability of programmable yaw, camber, vertical load, vertical sink rate, wheel velocity and wheel acceleration. This allows for an accurate simulation of the forces and moments an aircraft tire experiences due to ground loading and maneuvers. A photograph of a tire undergoing testing on the programmable dynamometer is shown in Fig. 18. Program control is accomplished by solid state electronics and PDP 11 analog computers. A summary of the available test parameters of the Programmable Dynamometer is shown in Table II.

The programmable dynamometer can measure all the tire properties that the tire force machine can measure, and can include the effects of dynamic variation of load and tire rotation. Thus, a correlation between static, quasi-static, and transient tire properties can be made.
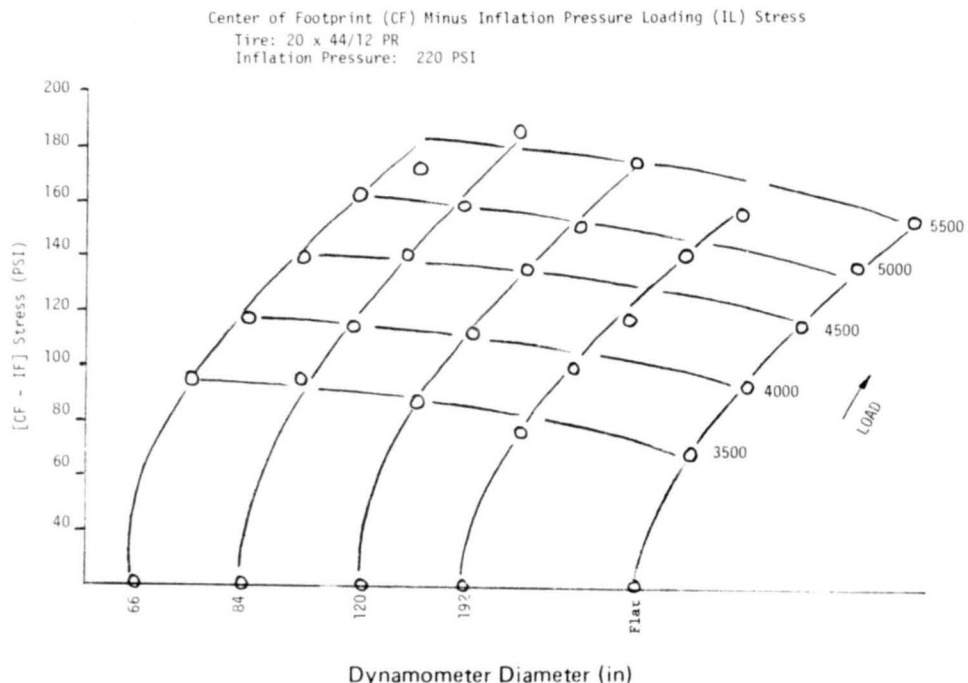
Center of Footprint (CF) Minus Inflation Pressure Loading (IL) Stress
Tire: 20 x 44/12 PR
Inflation Pressure: 220 PSI

Dynamometer Diameter (in)
FIGURE 17 NORMAL STRESS VS SURFACE CURVATURE AND LOAD

16
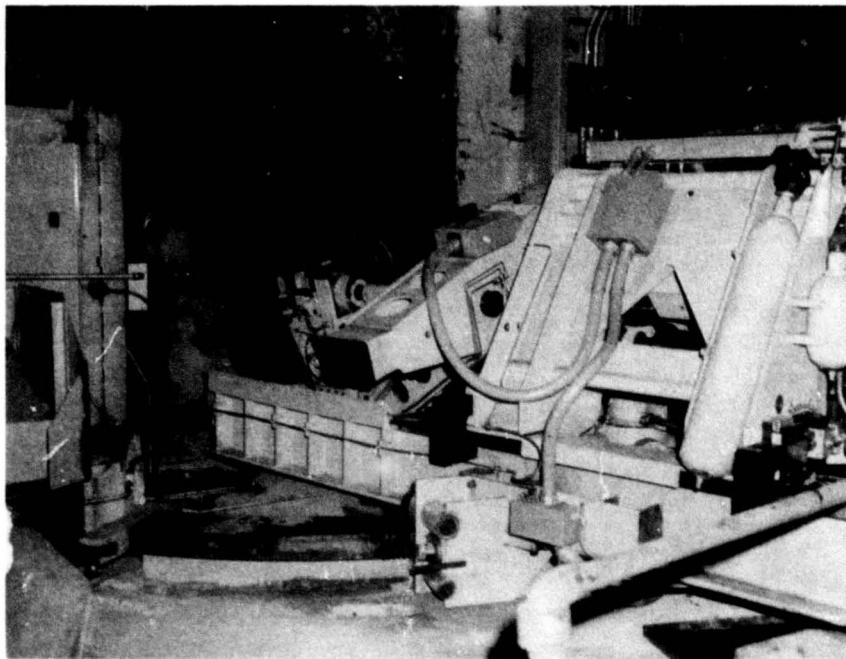
FIGURE 18   TIRE UNDERGOING TEST ON MODIFIED DYNAMOMETER

Taxi Takeoff Test
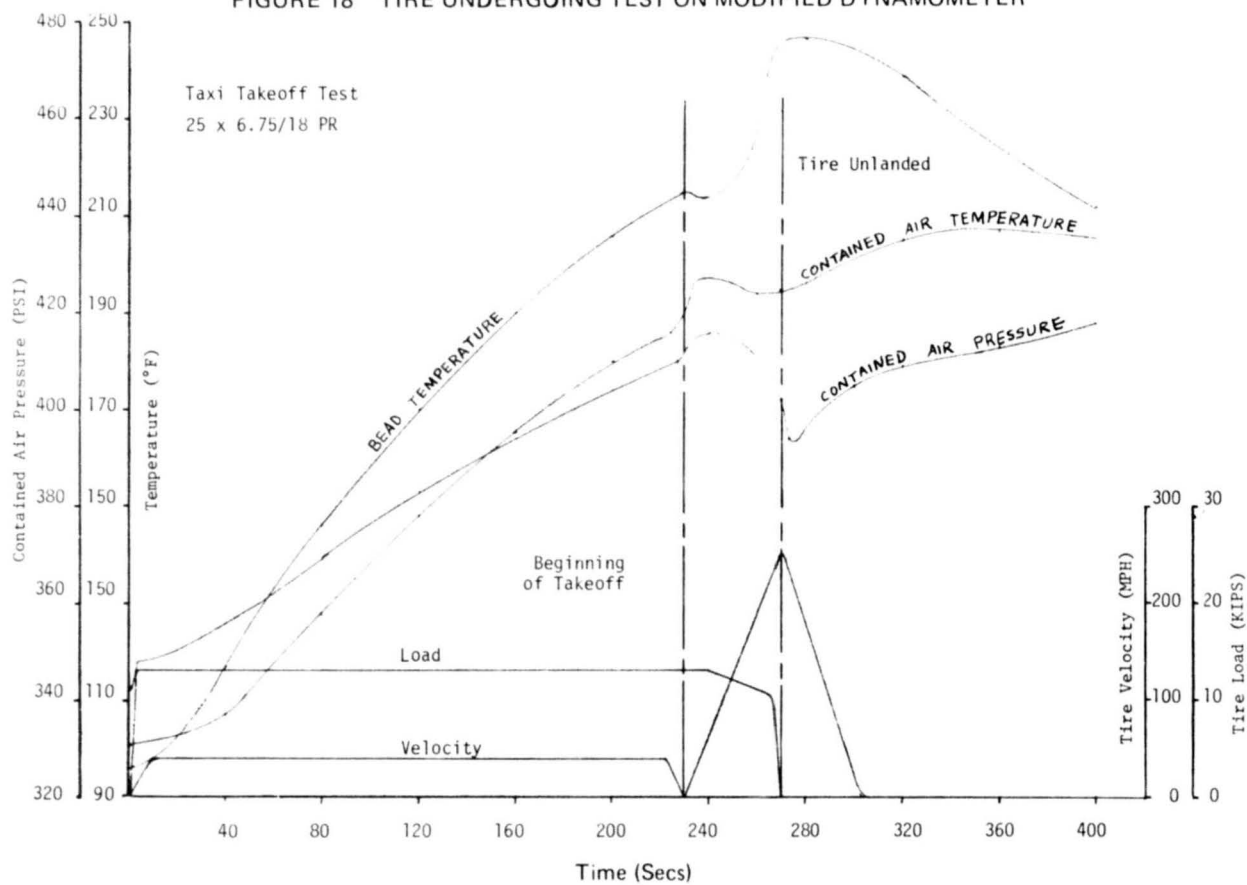25 x 6.75/18 PR

Tire Unlanded

CONTAINED AIR TEMPERATURE

CONTAINED AIR PRESSURE

BEAD TEMPERATURE

Beginning
of Takeoff

Load

Velocity

FIGURE 19   TAXI – TAKEOFF LOAD, SPEED, AND TEMPERATURE PROFILE

17

Table II

Dynamometer Specifications

Velocity	350 MPH
Flywheel Diameter	10 ft.
Max. Acceleration	24 ft/sec^2
Drive	3 Reliance DC Motors, 1150 HP

Tire Test Capability

Max. Tire Size	56 x 16 - 56 in. Outside Diameter
Min. Tire Size	18 x 5.5 - 18 in. Outside Diameter
Max. Vertical Load	100,000 lbs.
Max. Vertical Stroke	14 in.
Max. Sink Rate	60 in/sec
Max. Yaw	±20 Degrees
Max. Cyclic Yaw	±4 Degrees at 2 Hz
Max. Camber	±20 Degrees
Max. Cyclic Camber	±3 Degrees at 2 Hz

Data Recording

Contained Air Pressure	500 psig
Contained Air Temperature	0-300°F
Forces in 3-Directions	*
Moments about 3-Axes	*

*Data is sampled 20 times per second and stored on magnetic tape.

In addition, the effects of carcass temperature on tire lateral properties can be measured on the programmable dynamometer. The internal stress generated in a tire during the cyclic contact of the tire with the surface pavement produces heat build up. The temperature of an aircraft tire after taxiing from the hangar area to the runway is gener_lly in the vicinity of 200 degrees Fahrenheit. A plot showing the tire load, tire velocity, contained air pressure, contained air temperature and bead temperature during a taxi take off is shown in Fig. 19. The lateral force (F_y) available during take off, therefore, is that force which is generated in tires with an average temperature in excess of 200 degrees Fahrenheit. A carpet plot of lateral force at 5 MPH and at various vertical loads and slip angles is shown in Fig. 20 for a small aircraft tire with a carcass temperature of 90°F and 220°F.

The mechanical properties of retreaded aircraft tires are also being measured at the Air Force Flight Dynamics Laboratory. Preliminary results have indicated that the self-aligning torque and lateral force of retreaded aircraft tires are less than that exhibited by non-retreaded aircraft tires. It is not known if this is a carcass or tread related phenomenon and will be further investigated. Carpet plots showing a comparison of the lateral force and the self-aligning torque of a retreaded and non-retreaded aircraft tire at the speed of 75 miles per hour are shown in Fig. 21 and Fig. 22.

Frequency response tests are conducted on the programmable dynamometer to study the transient behavior of aircraft tires, which is important in studying problems dealing with landing gear stability. One of these tests is a sinusoidal yaw test which is conducted to measure tire
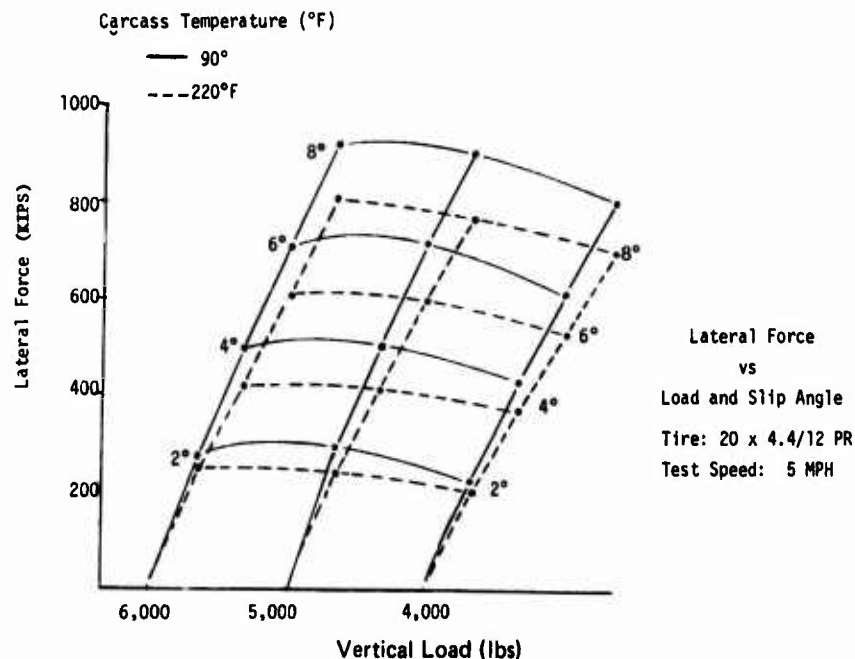

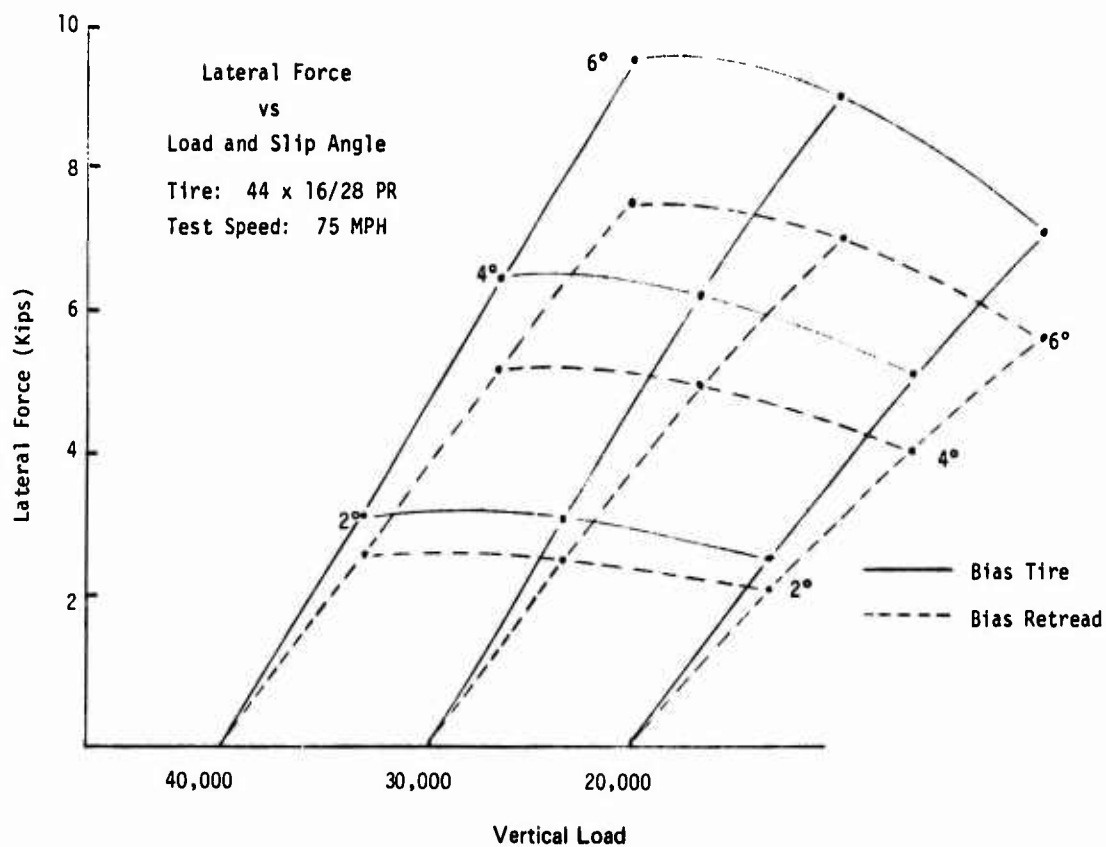FIGURE 20   EFFECT OF TEMPERATURE ON LATERAL FORCE

18

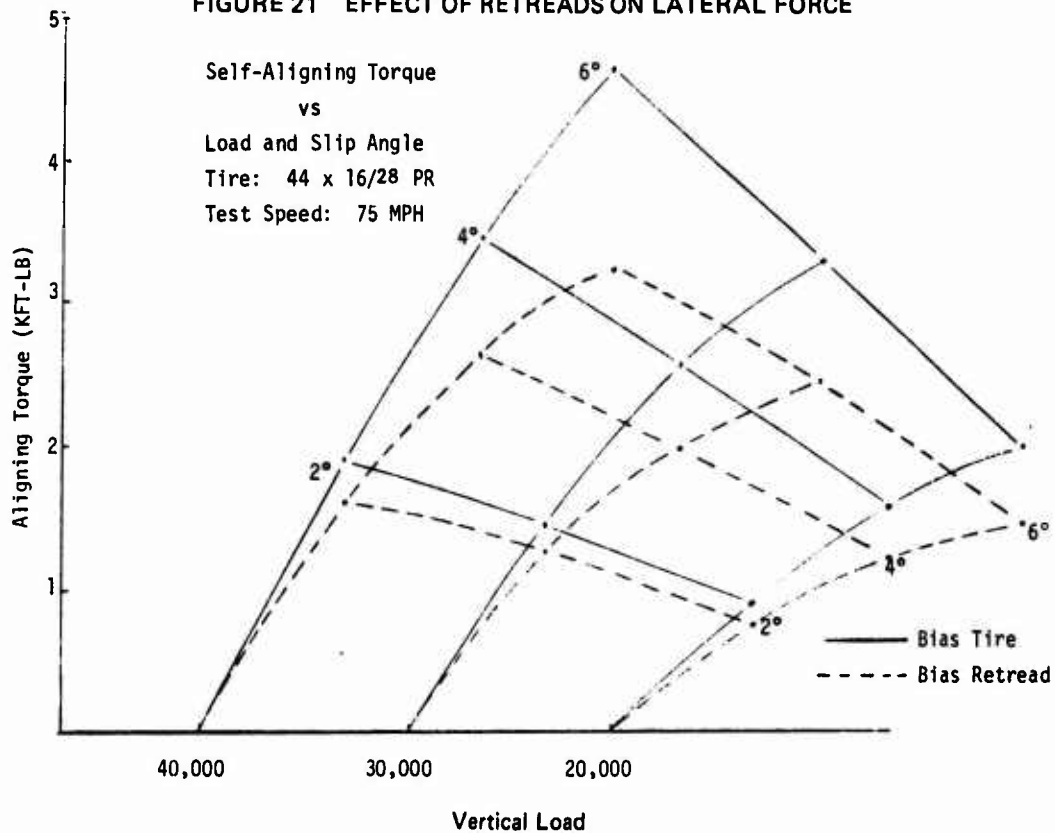FIGURE 21   EFFECT OF RETREADS ON LATERAL FORCE

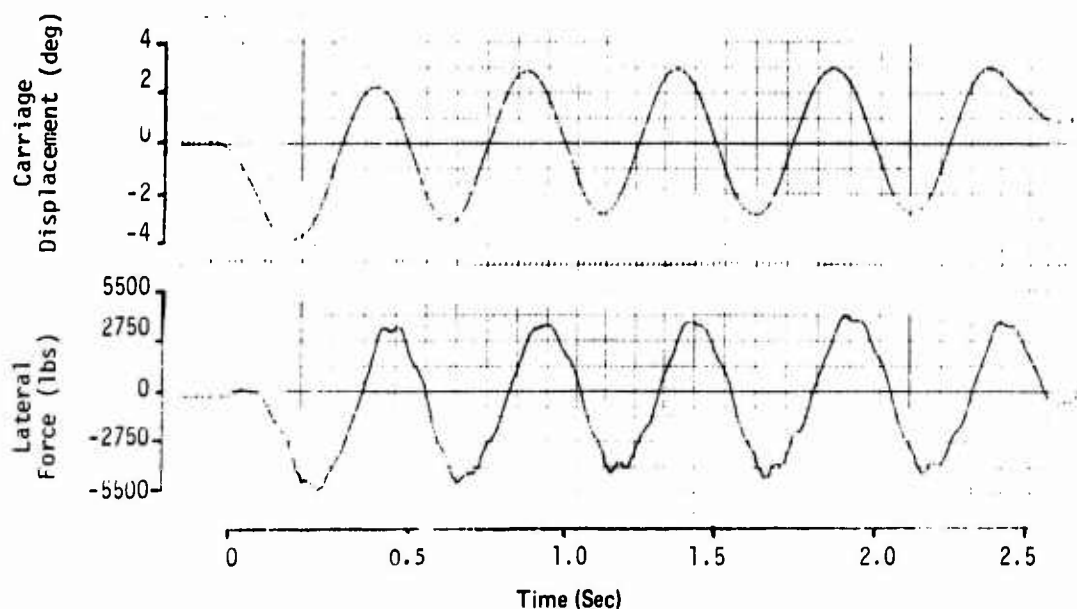FIGURE 22   EFFECT OF RETREADS ON SELF-ALIGNING TORQUE

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FIGURE 23   LATERAL FORCE RESPONSE TO SINUSOIDAL INPUT

properties important for shimmy studies. The forces and moments that are of primary interest in shimmy studies are lateral force (F_y), overturning moment (M_x) and self-aligning torque (M_z). The results of these tests show that the tire does have a response lag which is an important factor in a shimmy analysis. Fig. 23 shows a 2 hz, ± 3 degree angular displacement of the dynamometer carriage and the resulting lateral force response.

CONCLUSION

Knowledge of mechanical properties of aircraft tires is necessary in the design of landing gear and in the prevention and solution of landing gear problems. Data from the flat surface tire force machine and the 120 inch programmable dynamometer at the Air Force Flight Dynamics Laboratory can be used to establish the operating characteristics of aircraft tires and to establsih new tire design criteria and qualification test procedures. The data can also be used to modify and improve analytical techniques for predicting the dynamic behavior of landing gear struts, brakes, antiskid systems, aircraft steering and, in general, overall aircraft ground handling performance.

QUESTIONS AND ANSWERS

Q: Jim, I'd like to ask a question if I could. Is the Facility open for visitors?

A: Yes, it is.

Q: Could you tell them maybe how they could make arrangements to get in?

A: The person to contact is a Mr. Aivars Petersons, and he can be reached at Area Code (513) 255-2663.

Q: Would you expand a little bit on the subject you intro-

duced briefly about the difference in the force measurements on new tires and retreaded tires?

A: The tests we have done to date have indicated that retreaded tires exhibit lower cornering force and self-aligning torque than new tires of the same size, and from the same manufacturer. At this time, it is not known what creates the degradation of forces. It would have to be investigated further.

Q: You indicated that the stress for the curvature of the dynamometer has been normally taking the tire pressure rates in the tire up to higher pressure. What method are you recommending now?

A: Well, we're looking at various methods. One of the methods that I showed here was a load correction method and the stress curve that I showed had the center of pressure of the footprint shown at the various loads and at the various curvature of radii. What that indicates is that, in order to operate your tire at the same level of stress that would be seen on a flat surface, the proper procedure to use would be to decrease the load so that you would run at the same level of stress.

Q: The stress that you're measuring, is it the center line of the tire or the total tire?

A: We are measuring at various points along the periphery of the tire and the curves shown were an average of the readings from the stress transducers in the shoulder ribs.

Q: Isn't it also true in the tire central rim as well as the central group?

A: Yes it is, the same thing can be found. It's just that the transducers in the outer ribs has a cleaner curve.

Q: Your stress levels are not in the carcass plies?

A: We are not measuring cord stress, if that's your question. We're measuring the stress that is perpendicular to the tire at the surface.

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SIZE CRITICALITY STUDY IN NAVY AIRCRAFT TIRES

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INTRODUCTION

The U. S. Navy several years ago established the requirement for the Non-destructive Inspection (NDI) of rebuilt (re-treaded) aircraft tires. The following study is part of an on-going program to determine the criticality of defects found during NDI and to establish appropriate rejection criteria for the aircraft tires. The Navy requires NDI on tires with a speed rating greater than 160 mph. The majority of these tires are used on fighter and attack type aircraft which have only a single tire on each main gear and either one or two tires on the nose gear (Figure 1). If one tire fails, there is the possibility of damage to the wheel and landing gear, foreign object damage (FOD) to wings and fuselage, and the possibility of losing the aircraft and pilots.

The Navy aircraft tires are exposed to a more hostile environment than aircraft in other services or the commercial sector, in particular, the requirement for aircraft carrier operations of catapult takeoffs and carrier landings, more aptly described as controlled crash. Additionally, all Navy fields have arrestment cables of 1-3/8" diameter that are crossed during takeoffs and landings (Figure 2).

Therefore, this study becomes very important if it prevents the loss or damage to one aircraft due to a faulty tire. The defects to be examined are separations or disbonds as determined by holographic nondestructive testing. It is accepted general knowledge that separations in an aircraft tire will propagate. We wanted to determine the criticality of these separations: at what rate do the separations grow, at what size will the separations be detrimental to the tire integrity, and if there are locations in the tire where separations are more critical.

EXPERIMENTAL

The aircraft tires used in this study are the 26x6.6 size, 16 ply rating, Type VII used on the main landing gear of the Navy's F-8 aircraft. The tire is constructed with a reinforced tread, with the exact design varying with each manufacturer. The tire studied has two tread reinforcing plies approximately half-way between the bottom of the grooves and the carcass plies. The tires were obtained through the regular supply system or were rejects from a Navy contracted rebuilder. All the separations or defects were "natural", arising during the manufacture or the service life of the tires. None of the defects were intentionally made or programmed into the tires.
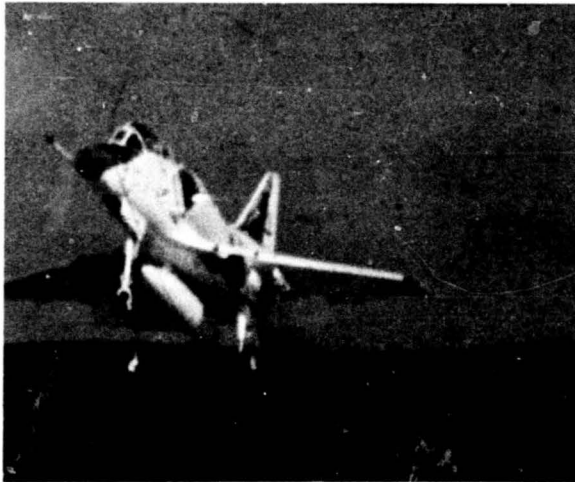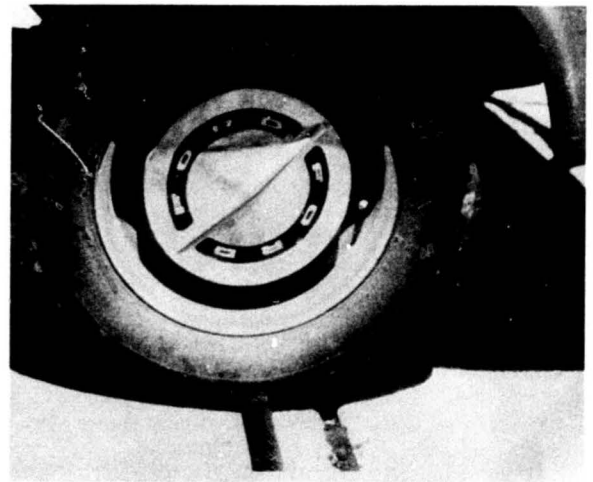

FIGURE 1
A-4 TAKING OFF

FIGURE 2
FIELD ARRESTMENT CABLE
NOTE DEFLECTION OF TRUCK TIRE
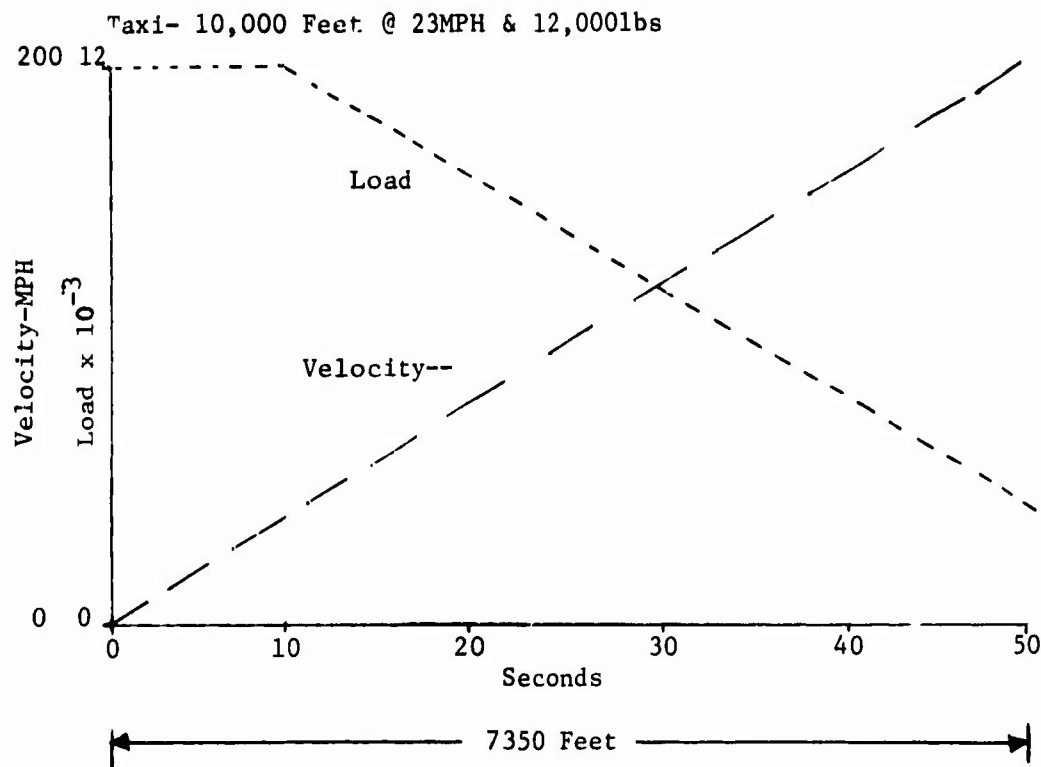
Taxi- 10,000 Feet @ 23MPH & 12,000 lbs

FIGURE 3   DYNAMOMETER TEST CYCLE

The tires were inspected with an Industrial Holographics Tire Analyzer equipped with a krypton laser. From the hologram, a map of each tire was produced. As each tire was inspected, the same map was used, to more easily see trend development.

The dynamic testing of the tires was performed on the 120 inch diameter dynamometer at Wright Patterson AFB (WPAFB). The test performed was the taxi-takeoff cycle as used by the Navy in Military Standards 26533 and 3383. The test consists of a taxi for 10,000 feet at 23 mph and 12,000 lbs. load. The tire is stopped and run through the simulated takeoff at 0 to 200 mph in 7,300 feet and load initially 12,000 lbs. decreasing to 1,200 lbs. at lift off (Figure 3). As part of the qualification tests the tires must successfully complete 50 cycles of the above test.

The tires were initially NDI and then sent to WPAFB for testing on the wheel. The tires were run through 25 cycles of the taxi-take-off (TTO), or until failure, with NDI being performed every 5 cycles. Those tires that had survived 25 cycles were then cycled to failure.

The following three examples serve to illustrate some of the different type of anomalies and locations across the tire tread.

The format is a map of the tire divided into four quadrants, starting at the serial number at 0° and preceeding clockwise

around the tire. Anomalies detected during the initial inspection are marked on the grid in black; after 5 TTO cycles, in blue; and after 10 TTO cycles in red.

In the first example, Tire N8 (Figure 4) only one separation appeared initially. This separation was 3/4" diameter and located in the crown at 235°. After the first series of 5 TTO the initial separation had not grown, but the tire had developed three new separations of 3/8" diameter at 45°, 285°, and 360°.

After 10 TTO cycles, the initial separation at 235° had grown to 1 inch and the other separations had grown to 3/4 inch and 1 inch. The testing was continued, and the tire eventually failed after 28 TTO cycles.

In the second example, tire N4 (Figure 5), only a weak area in the second quadrant showed initially. After the first series of 5 TTO cycles, the tire had developed numerous small separations in the shoulders ranging from 1/8 to 3/4 inch, and one area in shoulder, centered at 45°, that was characterized as "weak" but with no actual separations.

After the next series of 5 TTO, all separations had grown, one at 70° from 1/4 to 2-1/2 inches. The "weak" area at 45° had developed a series of 5 separations. The tire then failed on the 15th cycle of taxi-take-off, throwing the entire tread.

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FIGURE 4

23

$\Sigma_0 \quad \Sigma_5 \quad \Sigma_{10}$

Customer	Tire O K		Size	House Number
NAVY	Special Study	✔	**26×6.6**	**N4**
	Reject			
Mileage **5 Taxi Takeoffs** each $H_0 \to H_1 \to H_2$	Retread Number **R$_0$**		Carrier In Out	Serial Number **40170125**
Date Received	Date Shipped		Shipper Number	Holograph Number And Date

Serial No. Up

B
S
CC
S
B

H_1 weak only - No Seps

weak Sep ¼"

2½"

$\frac{1}{4} \to 2\frac{1}{2}$

■ H$_0$
■ H$_1$
■ H$_2$

Q$_1$

B
S
CC
S
B

H_0 ½ weak in this region

$\frac{3}{8} \to \frac{3}{4}$"

Q$_2$

B
S
CC
S
B

Q$_3$

B
S
CC
S
B

½"
1" ¼"
½" ½"
½" 1"

¼" → 1"
⅜ → ½"
½ → 1"

Q$_4$

B = bead   S = shoulder   CC = crown center

FIGURE 5

24

$\Sigma_o - \Sigma_s$

Customer	Tire O K		Size	House Number
NAVY	Special Study	✓	26×6.6	N5
	Reject	•		
Mileage	Retread Number		Carrier	Serial Number
$H_0 \to 5\ T.T. \to H_1$	R_1		In Out	9-66-87671
Date Received	Date Shipped		Shipper Number	Holograph Number And Date

Serial No. Up

0 15 30 45 60 75 90

B
S
CC
S
B

■ H_0
ok
■ H_1

Q_1

90 105 120 135 150 165 180

B
S
CC
S
B

ok

Q_2

180 195 210 225 240 255 270

B
S
CC
S
B

H_0 - Very Early Failure Predicted

3° ¾ 2° ⅛

Q_3

270 285 300 315 330 345 360

B
S
CC
S
B

ok

Q_4

B = bead S - shoulder CC crown center

FIGURE 6

25

<u>Centerline Separations</u>

1/4" ——————→ 1"   25 Taxi-Takeoff Cycles

1/8" ——————→ 3/4"   25 TTO

"0" ——————→ 1 3/4"   25 TTO

1/4" ——————→ 1 3/4"   25 TTO

FIGURE 7   GROWTH OF CENTERLINE SEPARATIONS ON DYNAMOMETER TESTED TIRES

<u>Shoulder Separations</u>

3" ——————→ 17"   5 Taxi-Takeoff Cycles

1/4" ——————→ 7"   15 TTO

1/4" → 2.5" → 22"   10 TTO

FIGURE 8   GROWTH OF SHOULDER SEPARATIONS ON DYNAMOMETER TESTED TIRES

<u>Skim Coat Separations</u>

3" ——————→ Failure   1 Taxi-Takeoff Cycle

1" ——————→ 4"   10 TTO

4" ——————→ Failure   1 TTO

1" + 1" ——————→ 5"   5 TTO

5" ——————→ Failure   2 TTO

FIGURE 9   GROWTH OF SEPARATIONS FROM SKIM COAT ON DYNAMOMETER TESTED TIRES

In the last example, tire N5 (Figure 6), the tire exhibited 4 large separations and was predicted to fail early in the testing. It did fail by throwing the entire tread during the first take-take-off cicle, indicated by the cross hatching through all the quadrants.

Again, the Military Specification requires the tires to complete 50 cycles of the TTO for qualification. If the above tires had been on an F-8 aircraft, the least that may have occurred is a premature tire change, a loss of maintenance manhours, and placing the aircraft in a down status. There is a wide range of scenarios possible when 10 to 15 pounds of rubber flies off at 100 mph or greater.

RESULTS

The study involved 16 tires. After 25 cycles the tires were cycled to failure. Of the 16 tires only two passed the required 50 cycles of the MS specification. One tire developed a separation on the 50th cycle but would be expected to have failed within the next two cycles.

Analysis of the tires and holograms show that the separations can be divided into three groups with respect to the propagations:

a.   those centered in the crown,

b.   those in the shoulder,

c.   those on the skim coat of the first carcass ply.

The separations in each of these areas grew at differing rates.

The first area is defined loosely as under the crown but not extending to shoulders of the tire. We see growth of the separations is relatively slow and uniform in direction, progressing from 1/4 to 1 and 2 inches diameter after 25 TTO cycles (Figure 7). Even at 2 inches, a single separation did not cause a failure to occur.

When we examine the separations in the shoulder area, we see a dramatic change in the growth rate and shape of the separations. The separations grow to approximately 1 inch wide and progress lengthwise along the shoulder. The rate of propagation is considerably faster for separations originating in the shoulder (Figure 8), a 1/4 inch separation growing to 2.5 x 1 inch in 5 TTO vice 25 TTO for a centerline separation. When the shoulder separation became as long as 10 inches, failure of the tire was imminent.

In the two areas above, the separations were all in the carcass between 1st and 3rd carcass plies from the tread. The principal failure mode of the third type was propagation of separations on the skim coat of the 1st carcass ply (Figure 10). This was experienced on only one carcass manufacturer. The propagation rate was very rapid, for instance a 3 inch separation (Figure 9) causing the tread to strip in the last cycle.

The failure occurs faster since the separations were above the carcass plies, and no structural bonding or tread retention occurs from the carcass plies.

SUMMARY

As we have seen from the experiment on the indoor test wheel, separations in the tires will become larger and

TREAD SURFACE

.018"

ORIGINAL TREAD RUBBER

INTERFACE— SKIM COAT
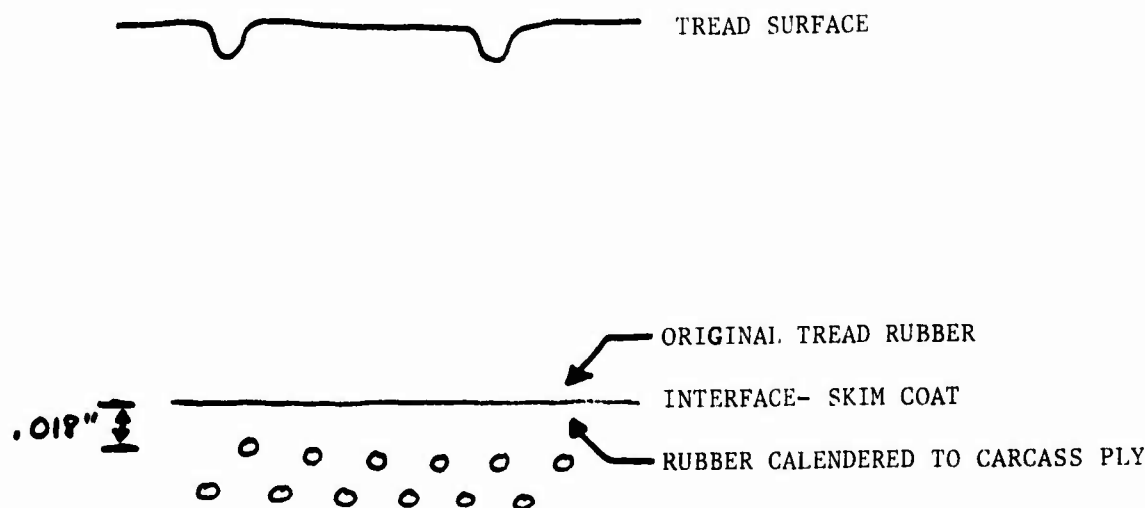
RUBBER CALENDERED TO CARCASS PLY

FIGURE 10   LOCATION OF SKIM COAT INTERFACE

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ultimately result in tire failure by the stripping of the tread from the carcass.

Based on these studies, the Navy is examining the present rejection criteria with respect to the size and locations of the separations in the tire. Thus it may result in a maximum size of 1/2 inch diameter in the crown and 1/4" in the shoulders. Another criteria may be to reject manufacturer A's tires containing a 1/4 inch separation and manufacturers B, C, and D with 1/2 inch separation.

Further studies are being performed which will investigate:

- different tire sizes with their related test parameter;
- carcass manufacturer;
- carcass age.

The Navy is a firm believer of NDI and its capabilities of detecting tires that may fail prematurely. Initially, NDI was required for the Navy high speed tires, rated over 160 mph. In the last several years, the Navy has required NDI on some critical low-speed tires.

QUESTIONS AND ANSWERS

Q: I have a question on this slide you have right here, the skim coat separations. What are the comparisons of these occurring in the tire region?

A: The skim coat I'm talking about is the skim coat on the first carcass ply. It is the rubber that is calendered to the first carcass ply. The separations occur at the rubber to rubber interface between the tread rubber components and the skim coat.

Q: In other words the first carcass ply means the ply next to the liner?

A: When I was referring to the first carcass ply I was indicating from the direction of tread area itself.

Q: We talk about it backwards.

A: Right. The tires that we investigated were of several different manufacturers and the number of actual carcass plys varies from manufacturer to manufacturer. The separations that we investigated were occurring between the first and second carcass ply from the tread area. It is more descriptive to call it between the first and second plies since this is generally where it occurred, rather than counting from the innerliner and saying it's between the eighth and ninth ply on carcass A or between the tenth and eleventh ply on carcass B, which would be quite variable.

Q: What size tire was related to the treads?

A: The tire is 26 inches in diameter and 66 inches wide.

Q: Did you have anything on the 40 x 14?

A: No, not yet. We have initiated testing on the 40 x 14 and the initial indication after the first phase of our testing shows that the rate of propagation is not as rapid as we see here.

Q: Do you have any intent to publish any of this data on the 40 x 14?

A: At this particular moment, no; but probably in the future, yes.

Q: The tires that were selected for this test program had natural anomalies. Did they have a previous service history or uniformity?

A: All the separations or anomalies in them were of a non man-made function. They were either developed in the tire during the dynamometer testing or they had occurred through a previous service life. The series of tires that we ran were both new and rebuilt tires so some had experienced a previous service life.

Q: You might mention they were all R-1 carcasses obtained from the Navy after a service tour except for the new ones, so there's only one service tour.

A: Yes, but the service tour that the tires see on aircraft can be highly variable even though they were R-1 levels.

Q: What was the age of the tires you tested?

A: They were of various ages. Some were at the time that this study was initiated, brand new, fresh out of the molds; others were up to approximately eight years old.

Q: Why is there a differing rate of separation with respect to the different rate of growth?

A: I would interpret it as being a higher stress load in the shoulder of the tires versus the center line. As indicated by the previous speaker, the increase in the tire pressure on the dynamometer to compensate for the deflection is overstressing the tire which would additionally be very critical in the shoulder area.

Q: Would that imply that if I started out initially with a 1/8" separation that they will all grow at the same rate?

A: I would not expect them to grow at the same rate. By the nature of the components that we're talking about, I would expect them to grow relatively similar for any one group, for instance, if they were all located in the shoulder of the tire.

Q: What is the correlation between the dynamometer tests and fleet usage?

A: I can't answer that question. I don't know if test data is large enough to indicate what variation in size growth that we will see. Since we're testing on the dynamometer versus testing out in the fleet, whatever data that we accumulate on the dynamometer is not necessarily translat-

able to what we can expect in the fleet. We have seen that some of the tires from fleet usage will not grow to such large dimensions as rapidly as they do on the dynamometer. But the advantages of using the dynamometer are, of course, it's a controlled environment. You can repeat the same test over and over again. In the Navy, each aircraft may fly five or six different flight profiles.

Q: Is there any relationship between the age of the tire and the speed of the failures?

A: No, none at all. Some of the new tires failed just as rapidly as the oldest tire did.

Q: I understand that you say that some of the tires were up to eight or ten years old?

A: Yes, some of the carcasses were.

Q: Some of the carcasses were still only R-1 positive. Were these tires stored as R-1's and what is the environment of the Navy warehouses?

A: The tires used in the experiment were retreaded less than a year before and had not entered the Navy supply. The Navy warehouse system is very extensive and the normal lag time within it can be very lengthy. For instance, I could go to a supply warehouse and pick out a brand new tire that is ten years old. The aircraft tires are supposed to be stored in a cool, dark location, away from hot pipes, fluorescent lights, and sunlight. With storage facilities from here to Alaska to the Philippines, including aircraft carriers, the storage conditions of the tires may not always be optimum.

IMPROVING QUALITY AND EFFICIENCY OF MILITARY
TIRES FOR LOW LIFE CYCLE COSTING

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INTRODUCTION

The purpose of this symposium is to report the progress of
the nondestructive tire testing technology which is a con-
tinuation of the reports presented during the last sym-
posium in Akron, Ohio in January, 1976.

The emphasis on Nondestructive Testing (NDT) studies is
placed on the development of technical and scientific
means of accurately identifying potential tire casing fail-
ures, or progressive casing deterioration within the carcass
composite. The reported studies demonstrate a satisfactory
progress in advancing the NDT capabilities in predicting
tire failures for the selection of reasonably strong casings
for retreads.

Nondestructive Testing measurements can easily detect the
mechanical degradation of tire casings. It cannot detect or
predict the physical changes and loss of properties in rubber
and adhesive bond components.

Although this phase of the NDT program has been satis-
factorily progressing, the program does not analyze the
degradation of rubber, the mechanism of tire failures, and
the relationship between ply separations and failures. As a
result, tire degradation continues to be a major problem,
because of high tire prices, short service life, and the re-
sultant waste of critical materials, when the whole tire is
scrapped as soon as, or before the tread is worn out.

Corrosion is a universal problem and a costly one. New
methods and products for reducing or preventing corrosion
have been introduced for both metals and rubber. How-
ever, at the same time, as industry seeks to improve pro-
duction, offer new products and increase efficiency, the
problems of corrosion and degradation are expanded. Esti-
mates indicate that the added costs for preservation of
rubber at the manufacturers' level, exceed $500 million a
year at the expense of the consumer, and the results are
still unsatisfactory.

The corrosion problem of metals has been substantially
diminished by alloying and anodizing methods. Alloying
of metals through the use of chemical treatments changes
their surface chemistry, and provides high strength at the
surface and resistance to corrosion and oxidation. The
same principle applies for the protection of rubber from
oxidation due to ozone and general environmental condi-
tions.

Treatment of vulcanized rubber for protection from ozone
attack and deterioration is relatively a new technology and
has been applied in the materials' development for aero-
space use. A special patented chemical antidegradant called
AGE-MASTER #1, was designed for this purpose and con-
stitutes a break-through in rubber protection.

Studies in polymer surface chemistry and test data, have
demonstrated the effectiveness of this new technology that
makes ozone susceptible rubbers immune to oxidation and
ozone attack.

The concept of surface treatment of rubber with AGE-
MASTER #1 was evaluated for aerospace application and
used in the development program for the U. S. Air Force,
Air Cushion Landing System (ACLS), Fig. A. The system
comprises a large, elongated, doughnut shaped inflatable
trunk (15 x 24 ft.), made entirely of natural rubber and
elastic nylon cord, which is attached to the underside of an
aircraft in place of a conventional landing system. The
composite material system was designed for high strength,
variable elastic characteristics, elastic recovery after ex-
treme deformations and resistance to fatigue and tear.

The environmental exposure problem was the most critical
factor, because of the requirements for maintenance of
elastic properties and mechanical integrity of the composite.

Treatment of rubber with AGE-MASTER #1 Rubber Pro-
tective Agent proved to offer an effective protection and
was used for the treatment of all ACLS rubber components.
The treated composites were successfully tested in taxi,
take-off and landing tests on various terrains in Florida and
in the Arctic Canada, and after three years of outdoor ex-
posure showed no signs of degradation due to ozone attack.
Untreated specimens of the composite which were exposed
outdoors cracked and deteriorated within 30 days.

This technology and performance data should be of signifi-
cant importance and interest for applications on military
tires, because it provides the means to control and extend
the service life of tires, maintain combat readiness, increase
tire reliability, and increase recapability of tires for reduced
costs. This novel approach makes possible the application
Life Cycle Costing (LCC) methods for the procurement
and maintenance of tires.

The following description of the basic mechanism of rub-
ber and tire casing degradation develops the concept of

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AIR CUSHION

LANDING SYSTEMS (ACLS)

An XC 8-A Aircraft was fitted with a new Air Cushion Landing System—a new development sponsored by the U. S. Air Force and Canadian Department of Industry and Commerce. The aircraft is able to take-off and land on a cushion of air. The Air Cushion System operates around a large rubber trunk, costing $500,000.

Unprotected samples taken from the trunks and tested showed cracking in 30 days. Thus, the useful life was very short. Those samples protected with AGE-MASTER NO. 1, did not crack or deteriorate after one year of outdoor exposure.

Trunks fitted to the aircraft and treated with AGE-MASTER No. 1, have lasted over four years without cracking or other signs of deterioration.

FIGURE A

tire protection, and gives examples of its practical utility in extending tire service life.

DEGRADATION OF RUBBER

The subject of rubber degradation and deterioration of tires is very extensive and technical. However, for better comprehension of the problem, and appreciation of the solution offered to diminish this problem, we are presenting only the highlights of the problem with factual results.

Natural and synthetic rubbers are particularly susceptible to atmospheric oxidation which causes polymer degradation, and loss of elastic properties and strength.

Oxidation by oxygen causes chemical and physical changes in rubber, and results in loss of tensile strength, resilience, elasticity and hardening. However, none of these are visually detectable. Precise measurements are required to detect the extent of such degradation and damage.

Ozone attack is another form of oxidation of rubber which causes rapid chemical and physical changes of the polymer

structure, and the damage to rubber is readily visible. Ozone attacks the elastomer at the double bonds and causes cleavage of its polymer chains. This cleavage initially forms microscopic cracking on the surface, which in a few hours or days can become quite large. Cracking develops in a direction perpendicular to the direction of stress. *FIG. 1* shows typical ozone cracking of rubber. Ozone cracking can propagate deep down to the tire core reinforcement and attack the adhesive bond of rubber to fabric, *FIG. 2.*

Ozone attack on rubber also results in another serious oxidation of rubber by the release of singlet oxygen ($^1O_2$), an extremely reactive form of molecular oxyten. Singlet oxygen ($^1O_2$) can diffuse a significant distance through solid polymers and can react rapidly with their functional groups. It also attacks the adhesive bonds of rubber to rubber plies.

Tire casing deterioration is caused by the combined effects of rubber aging, atmospheric exposure (Ozone, oxygen, heat and UV light), dynamic mechanical stress, and flexural fatigue. The deterioration starts with incipient separations in the tire casing structure and microcracking on the surface of the rubber, which often leads to questionable tire dur-

TYPICAL EXAMPLES OF OZONE AND WEATHERING DAMAGE

FINE CRACKING　　**MODERATE CRACKING**　　**SEVERE CRACKING**

WEATHER CHECKING　　**TREATED SPECIMEN NO CRACKING**
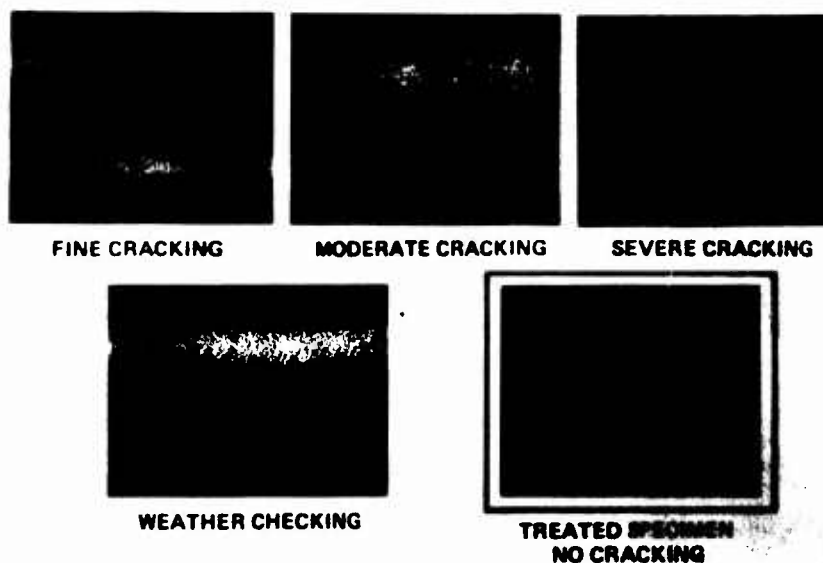
FIGURE 1

Typical examples of ozone and weathering damage. Natural rubber truck tire sidewall compound specimens showing different degrees of rubber deterioration caused by ozone, pollution, weathering and aging. Treated specimen shows excellent resistance to weathering and ozone attack.

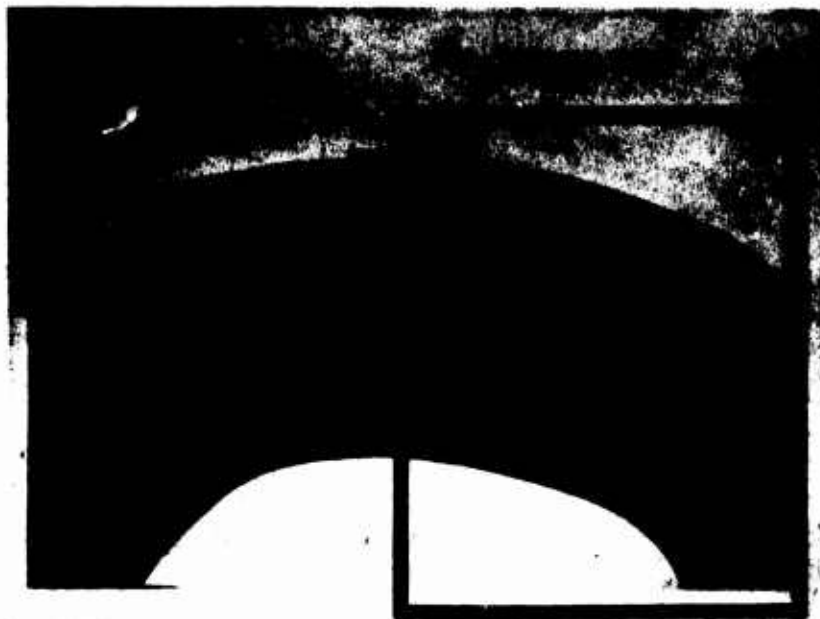## EFFECT OF OZONE CRACKING ON TIRE DEGRADATION

FIGURE 2

Side view of truck tire tread section showing depth of cracking. Treated groove with AGE-MASTER No. 1 shows no groove cracking. Untreated groove shows cracking extending into the fabric reinforcement (tire cord). This helps water and moisture get to the cord to start separation of tire plies and loss of tread on the road.

Tire section was exposed to 50 pphm Ozone (parts of ozone per hundred million parts of air) at 75°F, 36 hours exposure time. Fine cracking was observed on the untreated side in 4 hours, and propagated to very severe in 36 hours.

ability or premature failure. In severe cases, the degradation may cause rapid cracking of the sidewall and tread grooves, ply separations, sidewall flex breaks and reversion at the shoulder and tread areas.

Sidewall and tread groove cracking, which often reaches deep into the fabric reinforcement of a tire casing, can accelerate the problem of ply separations by the absorption of moisture or water through the capillaries of the cord filaments; significant amounts of moisture can be trapped in those areas, and develop in top-blows and separations when the heat build-up of the tire reaches to elevated temperatures.

Current industrial practice is to use various antidegradants and waxes in the rubber compound to promote the necessary resistance to oxidation and aging of rubber. However, from normal performance and laboratory tests, we can determine that there is a serious deficiency in their protective action, which results in premature failures and total replacement of tires.

THE NEED FOR EFFECTIVE PROTECTION OF TIRES

Aging of rubber is a complex phenomenon, and a major factor affecting tire life. Other factors are: Underinflation, overload, and speed. All these factors can be easily controlled and constitute part of tire maintenance programs in commercial fleets. Aging and oxidation are either neglected because the consumer cannot find an effective product for maintenance, or are totally ignored by the consumer because the information on this subject is limited to the rubber chemist, only.

Military tires which are expected to last longer than commercial tires (5-6 years), because of low service mileage, require an effective protection for preservation. Such a protection will make possible the retention of carcass strength integrity for multiple recaps, and the procurement of regular off-the-shelf commercial tires as needed.

Procurement of off-the-shelf commercial tires for military use offers economic advantages, and supplies could be

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FIGURE 3

10.00 – 20 TRUCK TIRE

Exposed for 6 months outdoors in Los Angeles. Unprotected section developed cracking during the first month of exposure. Protected with AGE-MASTER #1 section showed no cracking at the end of the test period (6 months).

The test shows the tremendous difference in ozone and weather resistance brought about by this chemical treatment using AGE-MASTER #1.

TRUCK TIRES

FIGURE 4

This truck tire sidewall section represents a premium truck tire available in the market. The untreated section is severely cracked and deteriorated. The section treated with AGE-MASTER No. 1 did not show any degradation or cracking and retained its ozone, at 75°F.

readily available without the need of special orders under MIL-specifications.

The need for rubber protection is illustrated by the following tests performed on commercial truck tires, and rubber compounds. *FIG. 3* shows a truck tire with ½ of the sidewall and tread treated for protection and the other ½ untreated. It was inflated to rated pressure and was exposed outdoors in Los Angeles for 6 months. The untreated control section of the sidewall and tread grooves showed severe cracking which propagated deep into the fabric region. The treated section showed no signs of any degradation.

FIG. 4 shows a specimen of natural rubber truck tire sidewall compound with ½ of its surface protected and the other ½ unprotected. The sample was exposed to ozone at constant load simulating conditions of tires on military motor vehicles in storage. Again, the unprotected section showed severe deterioration due to ozone attack.

Samples of Natural/Diene rubber blend compounds used for tires were tested outdoors in Buffalo, NY., and at Riverside, CA., to determine their environmental resistance against identical specimens treated with AGE-MASTER #1 rubber protective agent. Table 1 briefly shows the test results. The samples represent high quality rubber compounds with various antioxidant and antiozonant materials in the rubber matrix. In all cases, the rubber treated with AGE-MASTER #1 retained all its elastic properties without signs of any deterioration.

In addition to the molecular break-down which causes cracking of rubber, oxidation changes the original proper-

TABLE 1

OUTDOOR WEATHERING TESTS

A. PERFORMED AT RIVERSIDE, CA. FROM AUGUST TO OCTOBER 1977
   3 MONTHS TEST. ASTM D-518 B LOOP TEST.

RUBBER COMPOUNDS	TREATED WITH AGE-MASTER #1	RIVERSIDE, CA. RESULTS AFTER 3 MONTHS EXPOSURE
126 – Natural/Diene Rubber	No	Very Severe Cracking
126 – Natural/Diene Rubber	Yes	Crack Free
127 – Natural/Diene Rubber	No	Very Severe Cracking
127 – Natural/Diene Rubber	Yes	Crack Free

B. PERFORMED AT BUFFALO, NY. FROM JANUARY 1975 TO JANUARY 1976
   ONE YEAR TEST: ASTM D-518 B LOOP TEST.

RUBBER COMPOUNDS	TREATED WITH AGE-MASTER #1	BUFFALO, NY. RESULTS AFTER ONE YEAR
Natural Diene/Rubber	No	Very Severe Cracking
Natural/Diene Rubber	Yes	Crack Free

ties of rubber and affects the adhesive bond of tire components. thus, as aging of a tire increases, the adhesion of tread to carcass, rubber to cord reinforcement, and sidewall junctures decreases. This reduction in strength is the combined effect of oxidation flex fatigue. *FIG. 5* illustrates the effect of aging on the strength of rubber and adhesion to carcass. This degradation results in tread and ply separations, top blows, voids and general strength reduction of the carcass composite.

Oxidation also results in high heat build-up due to the loss of hysteresis and resilience of rubber. Heat has an adverse effect on the strength of rubber and adhesive bonds. As temperature increases, strength decreases in a linear fashion as shown in *FIG. 6*. A tire running at 210°F, is expected to be operating at 50% of the initial tensile strength of the rubber, 40% at 225°F and 30% at 250°F. This reduction in strength is accentuated by the oxidation process and may cause incipient separations, reversion and premature failure.

PREVENTIVE ACTION

The preceding discussion identifies the need for tire protection, and introduces a product to accomplish this task.

This new development for preservation of tires offers a surface chemical treatment which effectively shields and prevents oxidation and ozone attack of rubber. As shown in *FIG. 7*, the chemical treatment is accomplished by externally applying a specially designed chemical agent. The material penetrates deep into the rubber, and provides

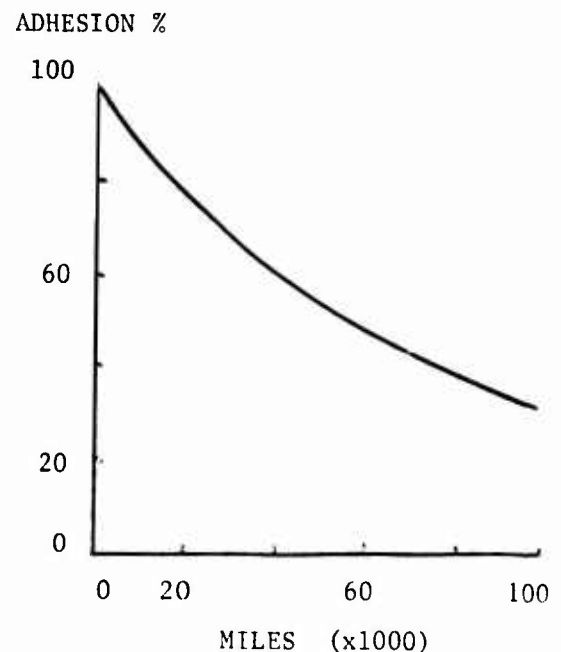### EFFECT OF AGING IN RUBBER STRENGTH AND ADHESION OF TREAD TO CARCASS

FIGURE 5

Reduction in tire compound properties due to aging and fatigue of rubber.

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a high concentration of an effective antioxidant at the surface and subsurface of the rubber where ozone attack and oxidation take place. It provides an intramolecular stabilization sysem and its activity is not impaired by flexing or scuffing during the service of a tire.

External treatment for the protection of tire integrity for more retreads is an essential part of tire maintenance. The advantages of tire protection are the following:

    Increase tire life and mileage performance
    Increase carcass life for more retreads
    Cooler running temperatures
    Reduced expensive road calls and labor
    Reduced cost per mile
    Reduced Life Cycle Cost

The protective agent available for the external treatment of rubber is AGE-MASTER #1, and it is produced by CHEM-PRO MFG. CO., Inc. of Buffalo, New York, under U. S. and Foreign patents.

SUMMARY

It has been demonstrated that the present problem of tire carcass degradation can be substantially diminished by chemical treating the surface of the rubber. This approach will contribute to sound tire carcasses for retreading, and will make possible the increase of the present number (10-15%) of re-built tires to the 70% level, as required by the Army.

The discussion and presentation of facts is to provide the Army with information on advanced technology in this field, which is available for immediate application.

For this reason, we are inviting you to explore with us this novel approach in applications concerning your particular studies in improving tire durability.

We also recommend the incorporation of this approach on future tire tests of military or aircraft tires.

As a final comment, I want to emphasize that protection of rubber contributes, substantially, to the preservation of energy related materials, and particularly petrochemicals used in rubber products.
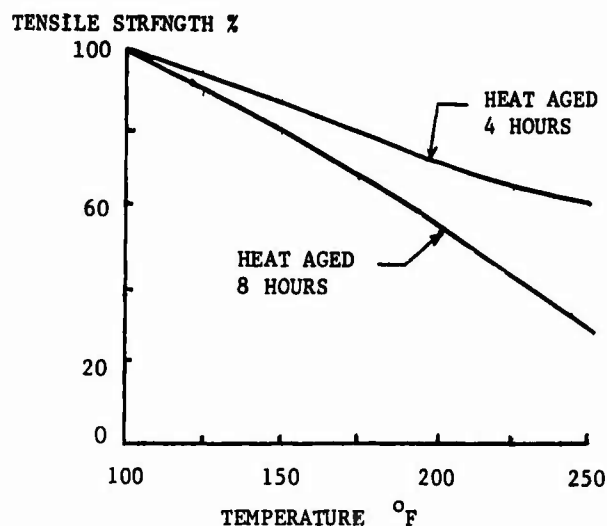
EFFECT OF HEAT IN RUBBER STRENGTH

FIGURE 6

Reduction in tensile strength of tire compounds with increase in temperature.

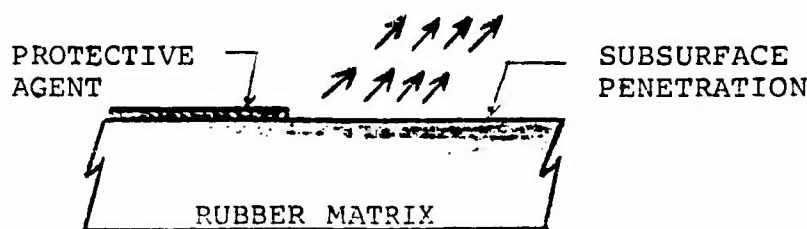### AGE-MASTER #1 EXTERNAL TREATMENT
HOW IT WORKS

FIGURE 7

Externally applied to vulcanized rubber, AGE-MASTER #1 penetrates deep into the rubber, and provides an effective intra-molecular protective system against oxidation and ozone attack.
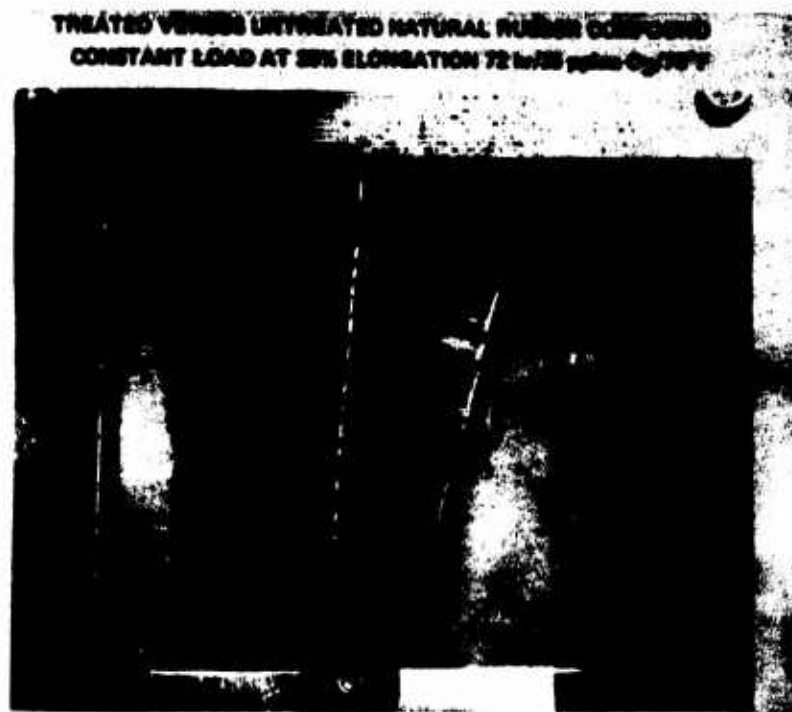
FIGURE 8

Natural rubber truck tire sidewall sample exposed to 35 pphm Ozone (ASTM D-1149) for 72 hours in an Ozone Chamber at 75°F. Shown here stretched to 25% elongation under constant load, cracking destroyed the untreated side, while the side treated with AGE-MASTER #1 did not crack at all.

The unprotected rubber lost all its elastic properties and strength, and it is a "dead" rubber. In comparison, the protected rubber is like new, alive, and retained all its elastic properties and strength.

QUESTIONS AND ANSWERS

Q: What is the ozone concentration that we were talking about under accelerated testing?
A: Most of the accelerated testing was conducted under ozone concentrations of 50-55 pphm (parts of ozone per hundred million parts of air). Other tests were also conducted under 100 pphm ozone, in conformance with specifications requiring extreme ozone resistance.
Q: Is it in an ozone chamber?
A: In an ozone chamber under controlled conditions for ozone concentration and temperature at 75°F.
Q: Did the time of surface treatment and concentration make any difference in the performance of the product?
A: Yes, the best time to apply the treatment is as soon as the tire is cured, preferably at the final finish stage. If this is not possible, we recommend treatment as soon as possible while the tires are relatively new, because oxidation and ozone attack take place immediately after the tire is out of the curing press. Early treatment will render the best protection. Concentration is important.

Another advantage of this system is that you can use it during the service of the tire as a preventive maintenance program. Present tire maintenance programs require proper inflation, tire rotation and tire balancing. They do not include protective measures to prevent deterioration of rubber (side-walls, and tread grooves), due to weathering and environmental exposure. Protective coatings are used for the protection of houses and industrial installations from deterioration and corrosion. Surface treatment of metals is an advanced technology used to make metals stronger, and abrasion and corrosion resistant. But, for rubber and tires, we seem to be doing nothing for their protection. If we are very serious about protection of tires, there is one way that we can do it, and this is by using this novel approach of surface treatment of rubber. Treated radial tire sections tested under flex conditions in an ozone chamber showed no cracking at the flex area after 15 days of exposure. The same untreated sections showed flex cracking within 2 days under the same conditions (50 pphm ozone).
Q: How do you apply this?

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A: Apply AGE-MASTER #1 using a brush, roller, airless spraying or dipping. Application can be made at any time before use or during service. New tires, not treated by the manufacturer, can be treated by the user. Application is very simple. Manufacturers can treat tires before or after the final finish process. Treatment is completely dry in 15 minutes.

Q: Does your material actually migrate into the rubber to form a barrier around the double bond?

A: Yes. The material as applied, soaks into the rubber, and it is designed to be absorbed and deposited into the polymer structure. It provides an intramolecular protective system that cannot be removed by flexing or scuffing. The material does not react with the polymer structure or double bonds, but remains there to react with the elements (ozone, or singlet oxygen) and arrest them before they will attack the double bonds of the rubber. This is the function. The material penetrates into the rubber 1 to 3 mils. Penetration and absorption depends of course, on the type of rubber and compound formulation. Type of fillers, plasticizers, and porosity of the vulcanizates are factors controlling the rate of absorption.

Q: Have you had any interest shown in the deicer boot application?

A: Yes, Sir.

Q: Who treats the deicer? The O.E. manufacturer?

A: No. Treatment of deicer boots is done by airlines and the owners of private airplanes. They found out that AGE-MASTER #1 is very efficient in protecting the deicer boots, even though they are made of Neoprene, which is considered to be an ozone resistant elastomer.

Q: Why doesn't B. F. Goodrich actually advertise this?

A: I don't know, Sir. We are in contact with B. F. Goodrich and of course they know about our material very well. They have tested it, analized it and they know its function and performance. So did Goodyear and major tire and rubber manufacturers all over the world.

Q: Given that the tire manufacturer is not prepared to do this immediately, how can the manufacturer of the tire do it within a few weeks? Can it be applied by the user after it's been in storage for two or three months before he gets it, and what is significant about it?

A: If a tire manufacturer is not prepared immediately to do the treatment in a mass production assembly line, he could do the treatment in a bay area, and as soon as the area is available without any special equipment. The treatment can be applied by the user after the purchase of tires. It is recommended that tires be treated as soon as they are manufactured, because oxidation of rubber starts immediately after cure. The user should continue application as a maintenance procedure to protect new surface exposed, as a result of sidewall scuffing and wear.

The significant factor between treating a tire after manufacturing and a new tire that was stored in a warehouse for a period of time, is that the tire from the warehouse has been already oxidized and already attacked by ozone. Microcracking which may develop as a result of this exposure, is the initiation of rubber degradation. Treatment of this tire will prevent propagation of cracking, and reduce the possibility of early failure. Military tires in storage at various depots or in transit may severely deteriorate before any use. Early treatment of tires, therefore, for protection and preservation is a significant economic factor.

Q: Is there a time factor involved for how long this coating will protect?

A: From laboratory test data, and actual field service performance of treated rubber products, we can state that the treated products showed an outstanding resistance to deterioration, with a service life longer than their untreated counterparts. The Air Cushion Landing System trunk, for example, treated with AGE-MASTER #1 showed no deterioration due to ozone for as long as 4½ years of outdoor service and exposure under constant strain of at lease 25% (trunk's relaxed mode). Similar untreated trunk sections tested under the same outdoor conditions deteriorated in 30 days exposure.

When the surface is severely abraded and the treatment surface is removed, simple local application for the treatment of the new exposed surface is sufficient to provide the required protection.

The protective agent remains at high concentration on the surface and sub-surface where ozone attack and oxidation take place. This material gradually reacts with the ozone and forms a protective layer of an ozonite compound. This ozonite forms a barrier, so that ozone cannot attack the rubber, and the singlet oxygen does not penetrate deep into the rubber to cause damage to the tire casing. This is the protective system.

Our technology and studies confirm with the findings of the National Research Council of Canada. They have done an extensive study on the degradation of rubber, and they defined the factors which I presented in a very brief way. Their findings coincide with our findings and this is why we're trying to inform you on this development.

We have the material that works and does the job of protection and offers a solution to the problem of rubber deterioration.

To many of you who are not involved in rubber technology, the complexity of the problem may not be very obvious. However, this subject is very complex and extensive. Specifically on this subject, the State University of New York is offering a five day symposium next month, and a seminar on the rubber degradation and recent advances on the stabilization technology of polymers. You can see how extensive this subject is.

BEAD INSPECTION TECHNIQUES
BY
BENDING RIGIDITY AND CONTOUR MEASUREMENTS

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Ann Arbor, Mcihigan

INTRODUCTION

For many years, there have been only two practical bead-inspection techniques available to the pneumatic tire industry. The first of these is hand and visual inspection, which has been developed to a relatively high degree of skill by trained tire inspectors. Nevertheless, in many cases they are not able to find internal defects, particularly relatively small ones, and for that reason many tire companies have relied on a second inspection, that of x-ray or fluoroscopic examination of tires, to determine internal characteristics of tire beads. One of the purposes of this present paper is to discuss the development of methods for inspecting tire beads which do not rely on these two conventional procedures.

The ever growing use of radial tires leads to the suspicion that because of their particular construction, bead loads will generally be higher with radial tires than with conventional tires. While unusual incidences of bead failure have not been reported, nevertheless, tire beads do perform in a cyclic stress, or fatigue limited, environment. Increased retreading of radial tires is apt to result in the use of tire beads over two or more life cycles under cyclic stress conditions somewhat greater than would be the case with bias ply tires. For this reason, mechanized or quantitative bead-inspection techniques would be of considerable value to the retreading industry.

Our previous work on the development of inspection techniques for passenger car tire beads was in two areas. First, we examined the general stress state in a tire bead on an analytical basis. Information obtained from this analysis was used to pinpoint the most likely areas of tire bead failure.

A partial verification of this analysis was obtained by experimentally measuring bead wire forces at different locations throughout the bead bundle. These measurements showed a tendency for an effective stress concentration to exist in the first layer of bead wires, as predicted by analysis.

The second major effort of this program was a careful study of several possible techniques for determining flaws in worn tire beads. The techniques studied included use of x-rays, electromagnetic eddy current detectors, and mechanical

devices. It was concluded that a mechanical head stiffness monitoring system was the most practical means of identifying apparent flaws in tire beads. This device consisted of a modified belt-driven tire inspection machine instrumented with a displacement indicator which showed positions of unusual change in the bead contour and stiffness. These positions were often locations of severe bead damage including such surface flaws as cuts or chunks, as well as kinks, bends, and broken wires in the bead bundle.

Upon completion of these two studies, described in [1], it was decided that further modification and automation of the bead stiffness monitoring system was well worthwhile. Such modifications and use of the resulting apparatus are the major subjects described in this paper.

BEAD-INSPECTION ADAPTER –
APPARATUS AND TEST RESULTS

From the results of previous work, [1], it was decided that the most practicable and usable device for detecting flaws in tire beads was a mechanical one in which variations in bead stiffness and contour could be continuously monitored around the circumference of the bead. In order to accomplish this in a practicable way, a bead-inspection adapter (BIA) was designed which could be attached to the spreader arm of an automatic tire inspection machine. This device does not alter the basic design and operation of the inspection machine. A photograph of such a machine with a BIA attached is shown in Figure 1.

The basic feature of the BIA is a displacement transducer which is spring loaded against the spreader arm of the tire inspection machine. Tire beads are inspected as follows: A tire is placed in the machine and the spreader arms are positioned so that their rollers are in contact with the inside edge of the bead. The arms are then spread by means of a pneumatic cylinder and mechanical linkage assembly. Attached to the arm is a displacement transducer which converts the displacement of the spreader arm into an electrical signal. A photograph of this BIA is shown in Figure 2. As the tire is rotated by the motor-driven cylindrical drums of the tire inspection machine, a continuous record of the displacement is displayed on an x-y plotter. One axis of the recorded graph represents the relative displacement of the transducer, while the other represents the position around the circumference of the tire bead.

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FIGURE 1
**AN AUTOMATIC TIRE INSPECTION MACHINE WITH
A BEAD-INSPECTION ADAPTER (BIA) ATTACHED
TO THE SPREADER ARM**

The BIA operates by displaying an electrical signal indicating deflection of the bead spreaders. In the vicinity of some bead anomaly, such as a bead kink, a bead cut, a bead chunk, a badly bent bead, or a broken bead, the bead spreaders will deflect abruptly causing a rather sharp signal to be produced in the electrical output of the system. This abrupt change is either due to an unusual contour change or bending stiffness. This unusual change, as compared with the signal from the rest of the head, can be observed and used to identify the presence of an anomaly.

It is interesting to note that each bead exhibits its own individual, reproducible signature from the output of the BIA. With some training, one can learn to "read" these signatures and identify not only the location but, in many cases, the nature of the flaw.

Having developed the BIA and installed it in an automatic tire inspector, a test and development program was begun to evaluate its usefulness. It was used to examine the beads of 70 tires. These tires were collected by a tire retread shop. They were selected by a reputable shop manager who sorted the tires on the basis of their bead condition. He purposely included many tires with known bead flaws, as well as some with good beads.

The major purpose of these tests was to establish a criterion for detecting flaws in the bead region of tires. These could be flaws such as cuts, chunks, bends, kinks and breaks.

As the 70 tires were tested, it became obvious that with a little training one could learn to "read" the bead signatures recorded on the x-y plotter and identify the presence of bead flaws. In addition, it became possible to recognize certain characteristics of the signature which often indicated the type of flaw present. A summary of these findings is illustrated in Figures 3 through 8.

In Figure 3, the photograph shows a typical bead with surface cuts. Above the photograph is a copy of the actual signature recorded for this bead on the x-y plotter. The shape of this sudden drop in signal is characteristic of serious bead surface cuts.

The photograph in Figure 4 illustrates a bead that was badly chunked to the fabric of the bead bundle. A copy of the signature for this bead is shown above the photograph and again illustrates a characteristic signal that typifies most chunked beads.
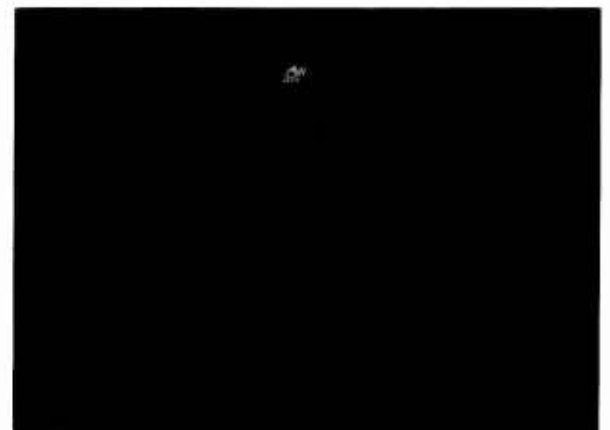

FIGURE 2
**BIA USED FOR DETECTING SUSPECTED FLAWS
IN TIRE BEADS**

**TIRE M283-2
1/2 IN. ROLLER**

Location of two cuts in bead of tire shown below.
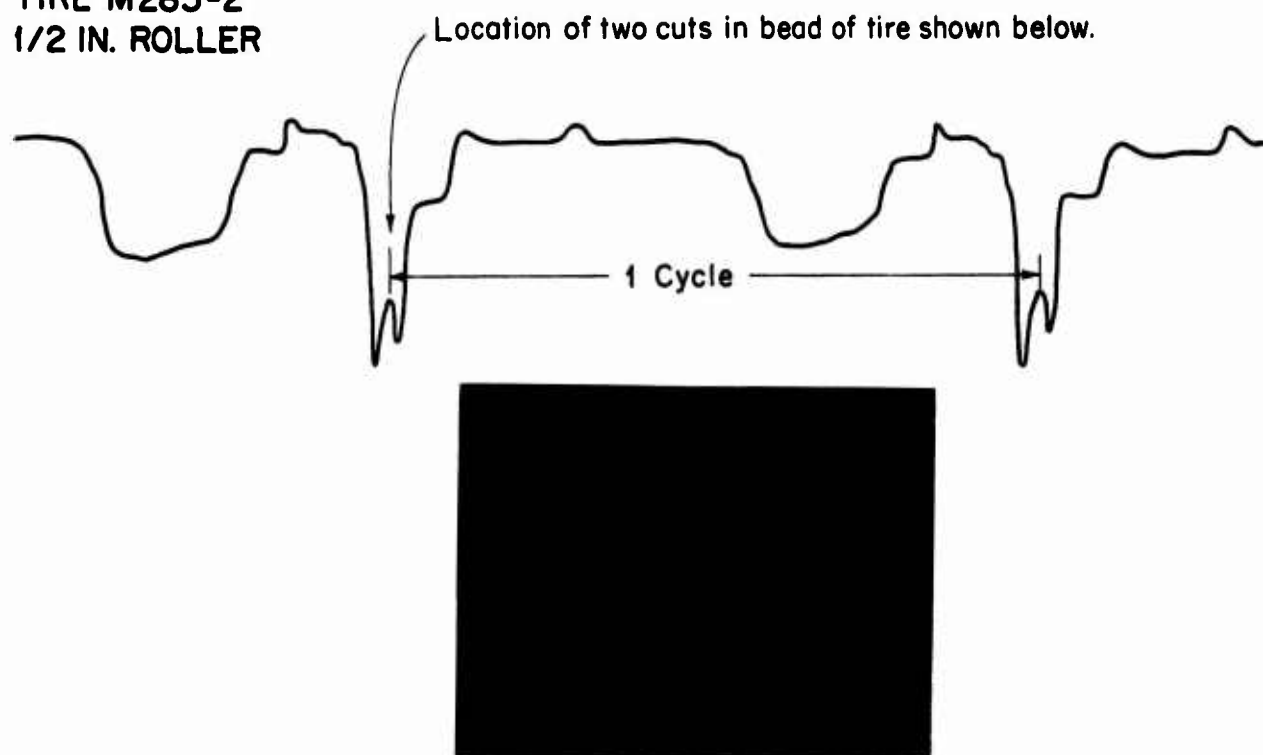
1 Cycle

FIGURE 3. BIA SIGNATURE AND PHOTOGRAPH OF A TYPICAL BEAD WITH SURFACE CUTS

Figure 5 illustrates a typical signal recorded from a tire bead with a severe bend. This type of flaw usually produces a large signal change. The photograph beneath the signature shows that severity of this bend. Even though this illustration seems to indicate that it is relatively easy to recognize a bent bead, it has proved to be the most difficult flaw to appraise consistently. All bent beads show a decrease in signal to some degree. However, it has proved difficult to judge the severity of a bead bend strictly from the magnitude of the signal change. To date, we have tended to be more critical of bead bends than have visual inspectors.

Figure 6 shows a dissected portion of a tire bead that was rejected because of a severe kink. This flaw was easily detected as the copy of the signature shows.

The photograph in Figure 7 illustrates the dissected portion of a bead bundle with several broken wires. As seen from the recorded signature, this flaw was also easily detected.

At the conclusion of this test program, the retread shop manager's written assessment of the tire beads was compared with the decisions made on the basis of records

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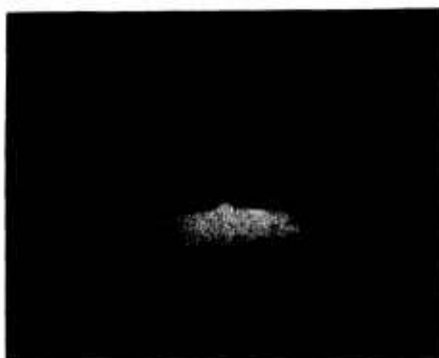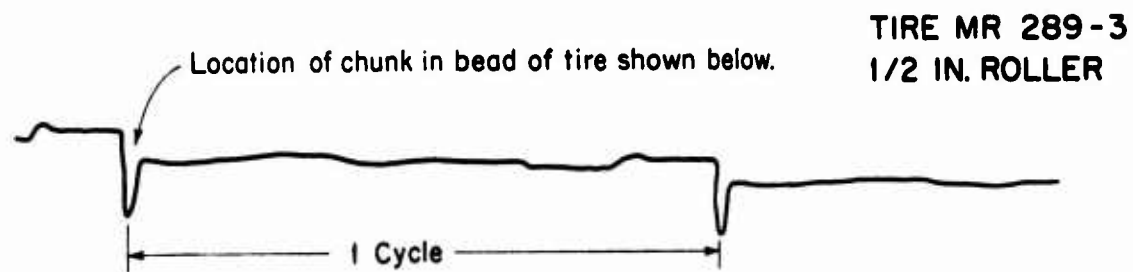
FIGURE 4. BIA SIGNATURE AND PHOTOGRAPH OF A TYPICAL CHUNKED BEAD
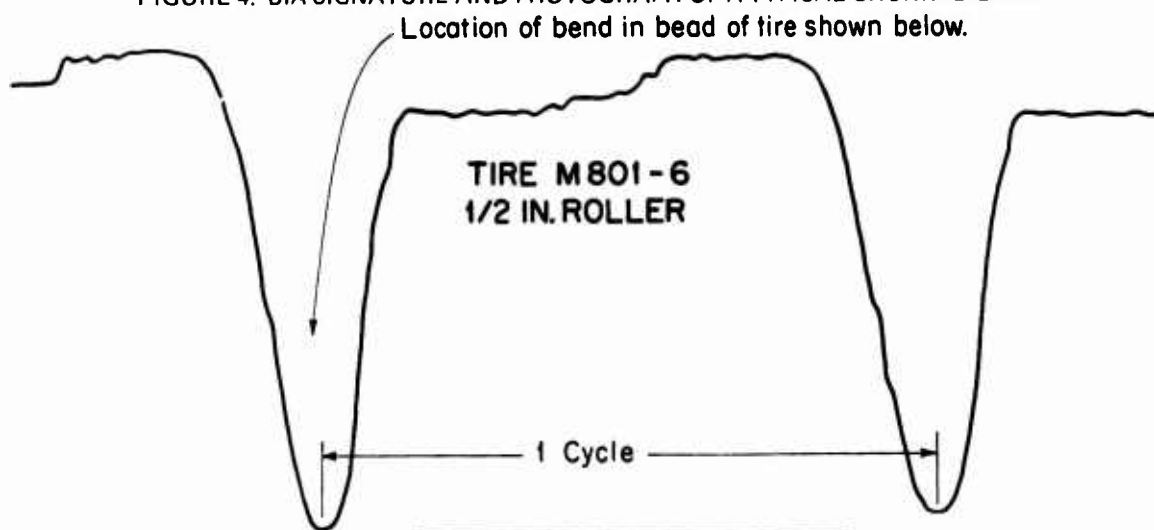
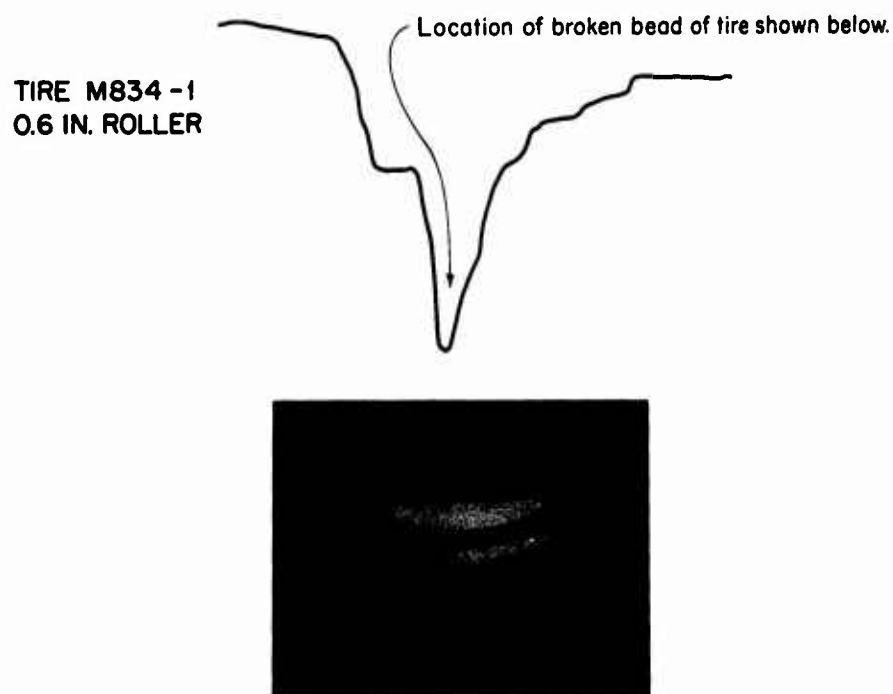FIGURE 5. BIA SIGNATURE AND PHOTOGRAPH OF A TYPICAL DISSECTED BENT BEAD

TIRE M290-1
1/2 IN. ROLLER

Location of kinked bead of tire shown below.

1 Cycle
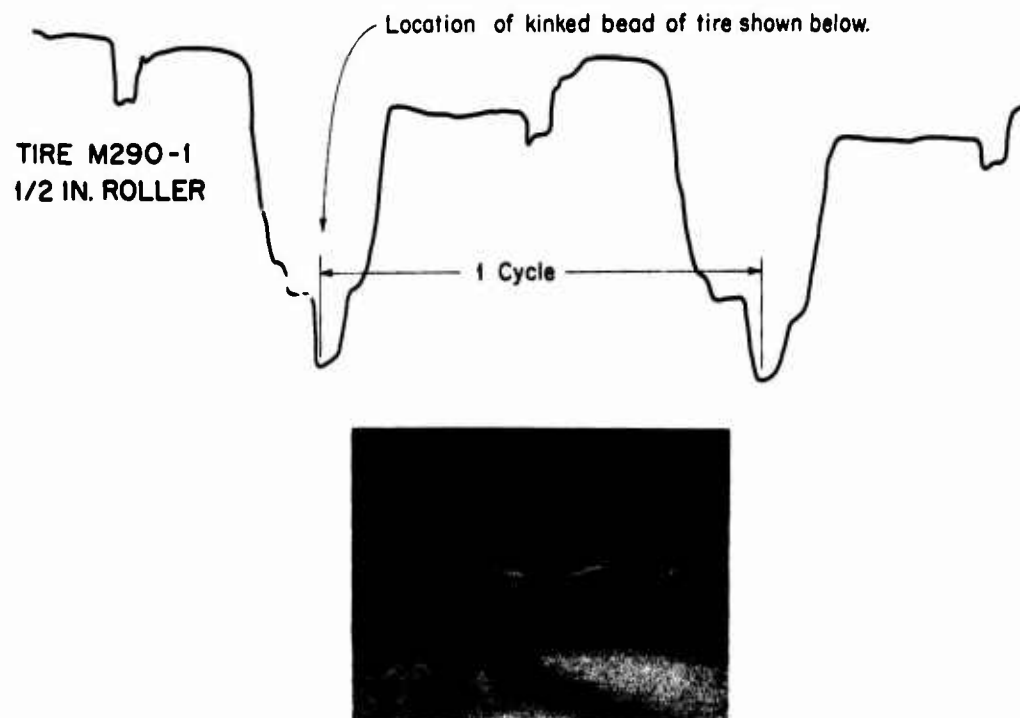
FIGURE 6. BIA SIGNATURE AND PHOTOGRAPH OF A TYPICAL DISSECTED KINKED BEAD

TIRE M834-1
0.6 IN. ROLLER

Location of broken bead of tire shown below.

FIGURE 7. BIA SIGNATURE AND PHOTOGRAPH OF A TYPICAL BEAD
DISSECTED TO SHOW A BROKEN BEAD

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from the BIA. A correlation between the acceptable and unacceptable tire beads as determined by the shop manager and the BIA is shown in Table I.

As seen from this table, the operator of the BIA rejected 56 of the 57 tires rejected by the manager of the retread shop. The BIA also accepted four of the 13 tires accepted by the shop manager. It should be noted that of the nine tires rejected by the BIA operator but accepted by the visual inspector, six involved tires with bent beads. In each of these six cases, the shop manager did not feel that the nature of the bend warranted rating the tire unacceptable. However, in the judgment of the BIA operator, each of these bends produced a recorded signature such that it was deemed appropriate to rate the tire unacceptable.

Of the 70 tires tested, there was only one that was rejected by the shop manager but accepted by the BIA operator. In this one case, the BIA failed to indicate the presence of a cut in the bead rubber that had penetrated to the wire within the bead bundle. This cut was also "against the grain," meaning that the cut was such that the rubber was pressed back into the cut region as the roller passed over the damaged area.

The results of these preliminary tests indicated that the BIA could be successfully used to discriminate between tire beads with no flaws and those with such flaws as cuts, chunks, bends, kinks, and broken wires.

Although the major purpose of this part of the test program was to develop criteria for the rejection of tires with bead flaws, another important conclusion was drawn from these tests. It became obvious that one could learn to "read" the tire's recorded signature and from this determine the presence or absence of bead flaws. However, the magnitude of the output signal was not the only factor in determining whether or not a bead was acceptable. Instead, it was necessary to observe sudden as well as large signal changes. One way of doing this is to graphically display the signal on an x-y plotter and then interpret the record. This

was the method used in the data discussed in the remainder of this paper.

A final test program was set up to examine 1000 tire beads with the BIA for the purpose of determining the reliability of this device as a means of detecting flaws in the bead region of tires. This program was divided into two parts. In the first part, 140 tires (280 beads) were selected by an experienced, professional tire inspector. Again, these tires were carefully chosen to include a wide variety of bead flaws, as well as some good beads.

These 280 beads were each examined with the BIA and then inspected visually by the inspector. A summary of the correlation between the BIA and the human inspector is shown in Table II. From this table, it is seen that in nearly 85% of the tests, the two results were in total agreement. Another 7% of the cases found the BIA operator rejecting a bead which had been approved by the visual inspector. Most of these disagreements involved bent beads. The remaining 9% of the cases were those in which the visual inspector rejected the bead but the BIA operator accepted it. Most of these cases involved beads that had been damaged on the outside surface of the bead where the roller of the inspection machine does not make contact but where the flaws are easily seen.

From the results of this 140 tire sample, it is concluded that the tire inspection machine with an attached BIA is capable of identifying beads with unacceptable flaws. However, it should be remembered that this was not a typical sample of tire beads found in the field. It was heavily biased toward beads with flaws – 57%. In the actual service, the fraction of unacceptable tire beads is much smaller.

The second part of this test program involved using the inspection machine in a retread shop to examine 720 more tire beads. These tires were randomly selected from the large inventory collected by the retread shop. Once again, these beads were examined independently by a human inspector and by the BIA operator. A summary of the cor-

TABLE I. – SUMMARY OF RESULTS OF VISUAL AND BIA INSPECTION
TECHNIQUES – 70 TIRES OF ORIGINAL TESTS

Human Inspector's Assessment of Bead Quality	BIA Operator's Assessment of Bead Quality	Number of Tires
Not acceptable	Not acceptable	56 (80%)
Acceptable	Acceptable	4 (6%)
Acceptable	Not acceptable	9 (13%)
Not acceptable	Acceptable	1 (1%)

relation between the two inspection techniques is shown in Table III. In this summary, it is seen that in nearly 93% of the cases, the BIA operator agreed with the human inspector. Of the remaining 7%, approximately one-half were rejected by the BIA operator but accepted by the human inspector. Of these disagreements, approximately 75% involved bent heads. In the remaining cases, the human inspector rejected the bead and the BIA operator accepted it. It was found that nearly half of these disagreements involved damages on the "flat" or outside of the bead area. Most of the remaining discrepancies involved beads with

cuts "against the grain" or ones with long, shallow chunks. It is also noted that the total percentage of unacceptable beads in this sample was approximately 25%, which was much less than the 57% found in the previous sample.

Several other important observations can be made from data collected in this program. For instance, as it became obvious that there was a relatively high percentage of tires with bead anomalies (25%), a complete listing was made of tire bead flaws. A tabulation of these is shown in Table IV. Here it is seen that nearly all flaws are as-

TABLE II. – SUMMARY OF RESULTS OF VISUAL AND BIA INSPECTION TECHNIQUES – 140 TIRES (280 BEADS) – PHASE I – 1000 BEADS TEST PROGRAM

Human Inspector's Assessment of Bead Quality	BIA Operator's Assessment of Bead Quality	Number of Beads
Not acceptable	Not acceptable	135 (48.2%)
Acceptable	Acceptable	100 (35.7%)
Acceptable	Not acceptable	20 (7.1%)
Not acceptable	Acceptable	25 (8.9%)

TABLE III. – SUMMARY OF RESULTS OF VISUAL AND BIA INSPECTION TECHNIQUES – 360 TIRES (720 BEADS) – PHASE II – 1000 BEADS TEST PROGRAM

Human Inspector's Assessment of Bead Quality	BIA Operator's Assessment of Bead Quality	Number of Beads
Not acceptable	Not acceptable	139 (19.3%)
Acceptable	Acceptable	527 (73.2%)
Acceptable	Not acceptable	28 (3.9%)
Not acceptable	Acceptable	26 (3.6%)

TABLE IV. – FLAWS DETECTED BY VISUAL INSPECTION – 383 DAMAGED BEADS

Percentage of flaws contributed by bead surface cuts	17.3%
Percentage of flaws contributed by bead surface chunks	60.8%
Percentage of flaws contributed by surface flaws on "flat" of the bead or outside	9.1%
Percentage of flaws contributed by kinked beads	3.1%
Percentage of flaws contributed by severe bead bends	9.4%
Percentage of flaws contributed by broken bead wires	0.3%

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sociated with damage occurring during the mounting or dismounting of tires. Although this program provides no remedy for such occurrences, it does provide clear evidence that there is a real need for improving mounting and dismounting techniques.

During this test program, a total of 29 beads with suspected flaws were examined further by dissecting the suspected area. Observations of these beads, in most cases, verified that the suspected flaws were indeed present. However, in a few cases no real flaws were found.

The results of the tests described above attest to the fact that it is feasible to design an adapter for a commercial inspection machine that can detect the presence of common bead flaws. The high percentage of agreement with visual and tactile techniques indicates that this inspection system can be reliable.

ACKNOWLEDGMENTS

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NEW APPROACH TO NON DESTRUCTIVE ENDURANCE
TESTING OF TIRES

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In general, tires are tested for endurance performance by either outdoor or indoor test procedures.

The outdoor test procedure determines the endurance performance of the tire by driving the tire continuously at specified loads and speed conditions on a test route to represent the extremes of customer usage.

The indoor test procedure determines the endurance performance of the tire by running the tires at specified loads and speed conditions on a smooth steel flywheel.

The majority of tire endurance tests are performed indoors. The indoor tests, which are generally run under far more severe conditions than those encountered on the road, provide an indication of the tire's durability in a fraction of the time which would be needed for equivalent outdoor tests. Department of Transportation (D.O.T.) standards specify test conditions and tolerance levels with respect to load, inflation pressure, speed, and ambient temperature.

This paper addresses the problems encountered by testing machines to meet these requirements and presents a solution to one particular problem, namely the regulation of the load to which the tire is subjected during the endurance test cycle.

Although not originally intended, the solution to the load regulation yielded another important feature which enables detection of the onset of tire failure. This feature provides the means to truncate the endurance test before massive destruction of the tire occurs, thus enabling the tire engineer to analyze the cause of failure in statu nascendi. Efforts to detect incipient failures using infrared and ultrasonic methods have been described in the literature (1, 2, 3). However, poor reliability of detection and the necessity for costly and sophisticated instrumentation to achieve detection curtailed wide spread use of these methods.

The problem of load regulation has plagued the tire industry since the introduction of closed loop hydraulic systems (Figure 1), replacing older type machines which used weights for loading purposes. (Figure 2)

The reason for introducing loading methods other than dead weight was obvious. Dead weight systems have inherent disadvantages. They are bulky, require supervision and cannot be programmed to perform automatic load changes. The approach to the solution of this problem must have looked simple; replace the dead-weight loading part of the tire endurance test machine with an automatic loading system. Moreover, it seemed to be a foregone conclusion, that whatever type of loading method would be used, it had to be a closed loop servo system. After all,

FIGURE 1

TIRE TESTING MACHINE (HYDRAULIC)

FIGURE 2

TIRE TESTING MACHINE (DEAD WEIGHT)

how else can one hold an applied load constant under varying pressure conditions. Consequently, machines were built based on servo systems which controlled either screw type or hydraulic loading systems. The results were far from satisfactory. The load which the system had to control consisted of an inflated rolling tire which exhibited features generally associated with springs. This property of the tire caused the servo system to overshoot the set point which frequently resulted in "hunting", that is, over correction and oscillation of the servo system. Moreover, tire force variations and long duty cycles (endurance tests can last up to 90 hours) placed high demands on the servo system and its associated electronic and mechanical subsystems, resulting in high failure rates.

It did not take long to realize that closed loop motor driven screw loading servo systems performed worse than piston type hydraulic systems. The motorized screw could not react fast enough, which caused large excursions around the load set point. These excursions exceeded the D.O.T. specifications which made the designers abandon the simpler screw type system and settle on the more complicated but faster hydraulic approach. Sophisticated electronic servo circuits had to be designed to assure correct servo action under the adverse conditions encountered by tire test machines.

Special servo valves were developed which had to withstand the continuous demands of the servo systems over prolonged periods. And yet, in spite of all these improvements, hydraulic servo tire loading systems continue to break down frequently, causing lost test time and excessive maintenance costs.

Serious doubts were raised as to whether the hydraulic systems were indeed designed to meet the specific test requirements and idiosyncracies of tires. It rather seemed that dead weight systems were replaced by hydraulic systems without the use of a thorough analysis of the task at hand. It was, therefore, decided to launch an investigation to cover the following points:

1. Review existing tire loading machines and their relative merits.
2. Analyze tire response and machine performance during typical tire endurance tests.
3. Determine absolute requirements of loading systems necessary to meet D.O.T. endurance specifications.
4. Based upon above conclusions, determine if a simple reliable loading system can be developed.
5. If affirmative – design said system and build prototype.

The conclusions based on steps 1 through 4 pointed out that it should be possible to design a loading system, which would perform all necessary functions, yet would be far simpler in design than present day hydraulic systems. Consequently, a prototype loading system was designed, built and put into operation in the Uniroyal Test Wheel Department.

The performance of the prototype met all design criteria. The controlled load stayed well within D.O.T. specifications and tolerances. The prototype accomplished these functions in a simple straight forward manner, without having to resort to complicated hydraulic closed loop servo systems. Because of its simple and rugged design, excessive downtime as experienced with hydraulic systems is practically non-existent. Since the system is basically an electro mechanical system, it can readily perform automatic load changes. Additional electronic circuits detect the onset of incipient failures in the tire, and provide means to truncate the test. In summary, the system is on par with commercial systems with respect to D.O.T. specifications, but outperforms these systems in efficiency and reliability.

HISTORY

The tire industry uses a variety of tire endurance test machines which employ different loading techniques. In general, those loading techniques fall into two categories:

1. Dead Weight Loading
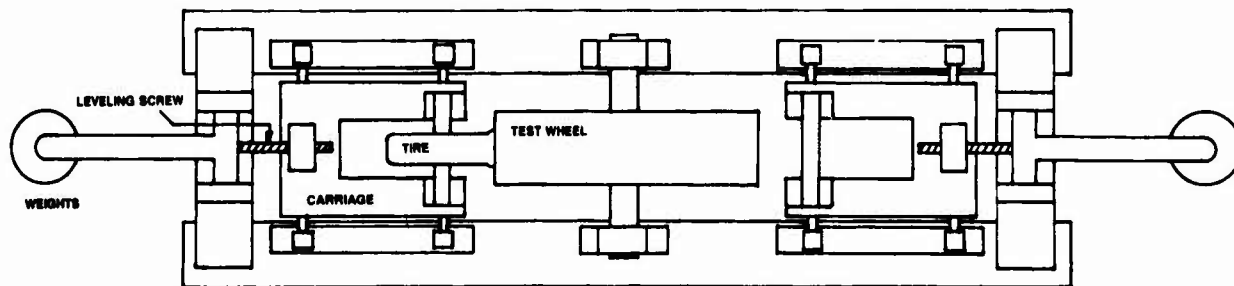2. Hydraulic or Air Cylinder Piston Thrust Loading

FIGURE 3
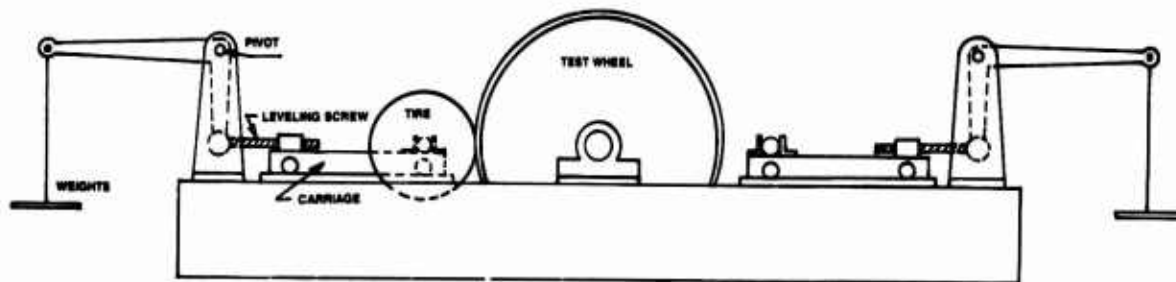"GOVERNMENT" MACHINE (TOP VIEW)
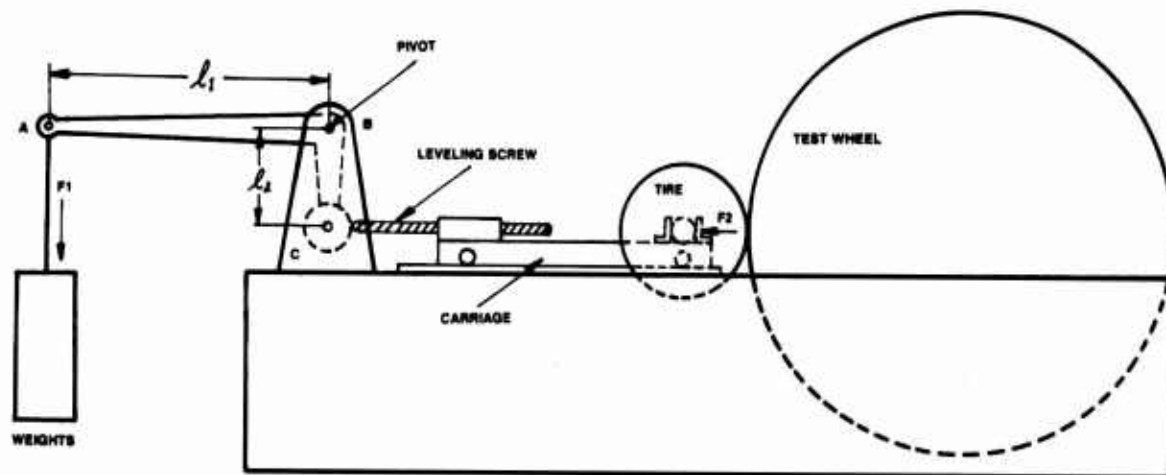
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FIGURE 4

"GOVERNMENT" MACHINE (SIDE VIEW)

FIGURE 5

DEAD WEIGHT LOADING SYSTEM, "GOVERNMENT" MACHINE

Dead Weight Loading

Machines which use dead weight loading invariably utilize mechanical leverage systems with different arm ratios to apply the load to the tire. The Government carriages, Mc-Neil carriages, Adamson machines, passenger Flat Belt and Lateral Thrust machines belong into this group. Since all of these machines use the same basic method but differ only in the application of same, it suffices to describe the operation of one typical machine in order to explain the underlying principles of the dead-weight loading group.

Figures 3 and 4 depict the top and side view of the Government machine* which uses the dead weight loading principle. The tire is mounted on a movable carriage which is forced towards the roadwheel through a lever-weight system.

As can be seen from the enlarged section in Figure 5, the moments in the X and Y axis around the fulcrum (B) of

the rigid lever are $F_1 \ell_1$ and $F_2 \ell_2$. Note that the lever is designed such that $AB \perp BC$

At equilibrium $\quad F_1 \ell_1 = F_2 \ell_2 \quad\quad (1)$

or $\quad\quad\quad F_2 = F_1 \dfrac{\ell_1}{\ell_2} \quad\quad (2)$

where F_1 is the force due to the applied weight (W) and F_2 is the force exerted by the roadwheel perpendicular to the tire axle, ℓ_1 and ℓ_2 are the respective lengths of the levers as measured from the fulcrum (AB and BC). Generally, the relationship between ℓ_1 and ℓ_2 is 3:1. This means that in order to load the tire with 1800 lbs., only 600 lbs. have to be applied at point A of the lever.

The above relationship (1) is true only if lever AB is balanced horizontally. Although the applied load (e.g. 600 lbs) does not change under imbalance conditions, the test load will be affected by the imbalance. It is, therefore, imperative to carefully balance the system in order to apply the correct load to the tire.

*So called, because these were the first tire testing machines built according to Bureau of Standards' specifications.

As mentioned, all dead weight loading systems use the principle of leverage in order to reduce the weights to manageable units. To illustrate this point, we shall show two more machines; the Overhead Adamson machine Figure 6, and the McNeil Carriage, Figure 7.

Although the design of these machines differs considerably from each other and from that of the Government machine, the underlying principle is the same. In each case, we see again the levers ℓ_1 and ℓ_2, the pivot point B and the levelling screw E.

Hydraulic Piston Thrust Loading

Machines belonging into this category replace the dead weight with a hydraulic cylinder-piston mechanism. The load-cylinder centerline concurrently intersects the tire spindle centerline at 90 degrees and the center of the tire both radially and in the plane of the tire. Thus, the force of the cylinder rod is the load on the tire. Figure 8 shows the essentials of a typical hydraulic machine. The tire is mounted on a spindle which is attached to a movable carriage. The carriage is free to move horizontally on two round ways, one mounted directly above the other. Ball bushings per way keep the drag low. The cylinder is flange mounted to the machine's end frame. The piston rod attaches to the carriage by means of a self-aligning rod end.

The loading system common to the machine just described and any other brand of hydraulic loading machines thus contains the following components:

Pump Motor
Hydraulic Pump
Reservoir and Filter
Oil Temperature Control System
Check Valves and Control Valves
System Pressure Regulator (Open Loop) or Feedback Regulation (Closed Loop)
Load Cylinder

Modern type hydraulic loading machines invariably use the closed loop approach which requires in addition to the above, a hydraulic servo valve controlled by cylinder mounted load cells and electronic circuitry.

A typical servo controlled system is depicted in Figure 9.

Operation is as follows:

The required test load (T+RA) is entered as an analog voltage into one side of a comparator. The analog voltage of this command signal is amplified in a power amplifier
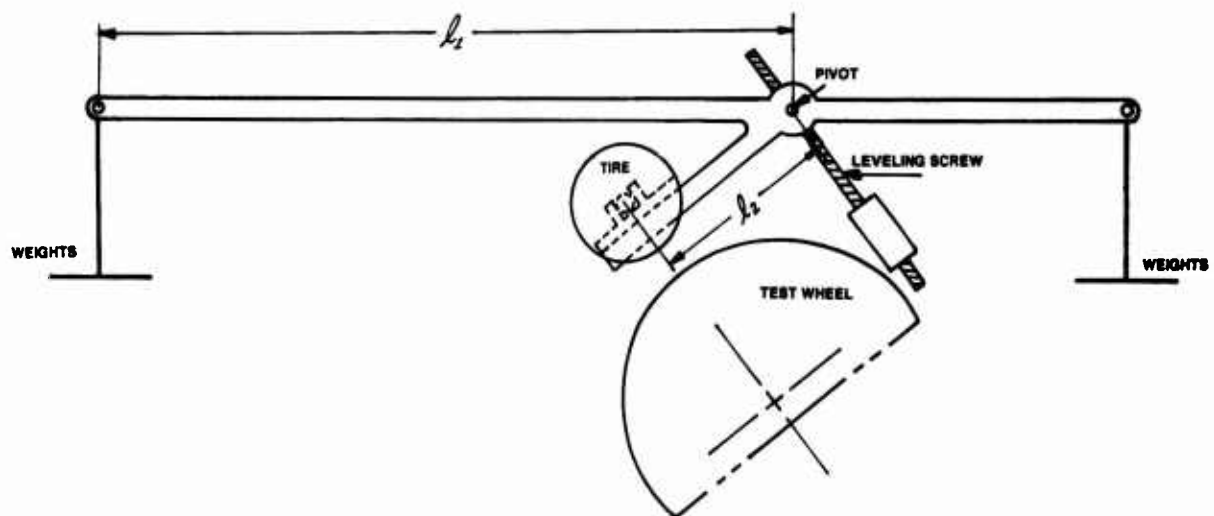

FIGURE 6

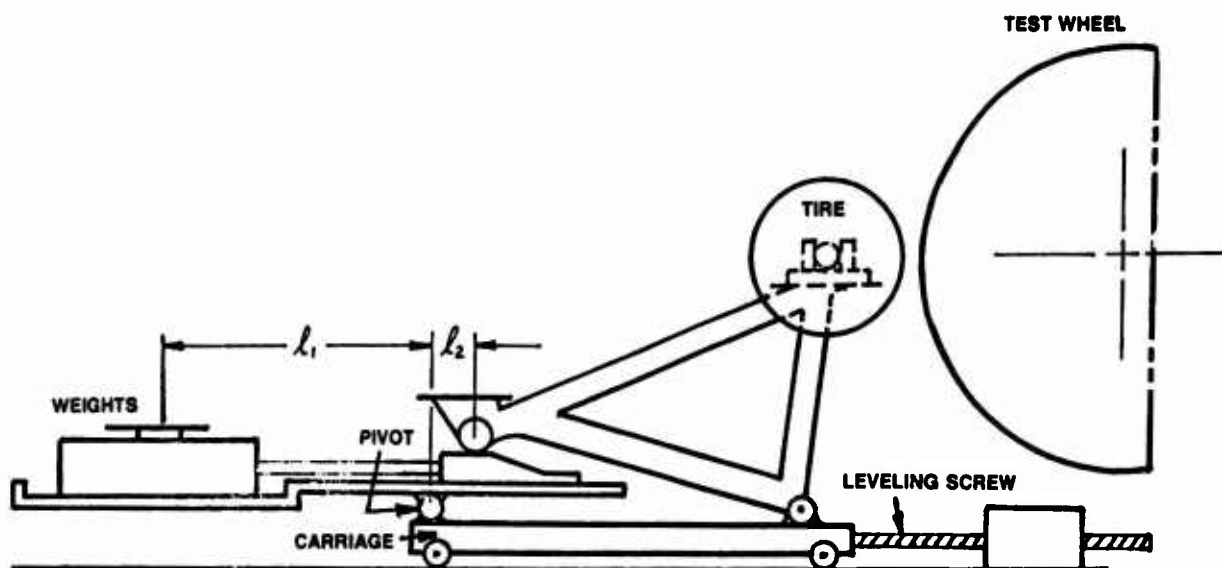DEAD WEIGHT LOADING SYSTEM, ADAMSON OVERHEAD MACHINE

FIGURE 7

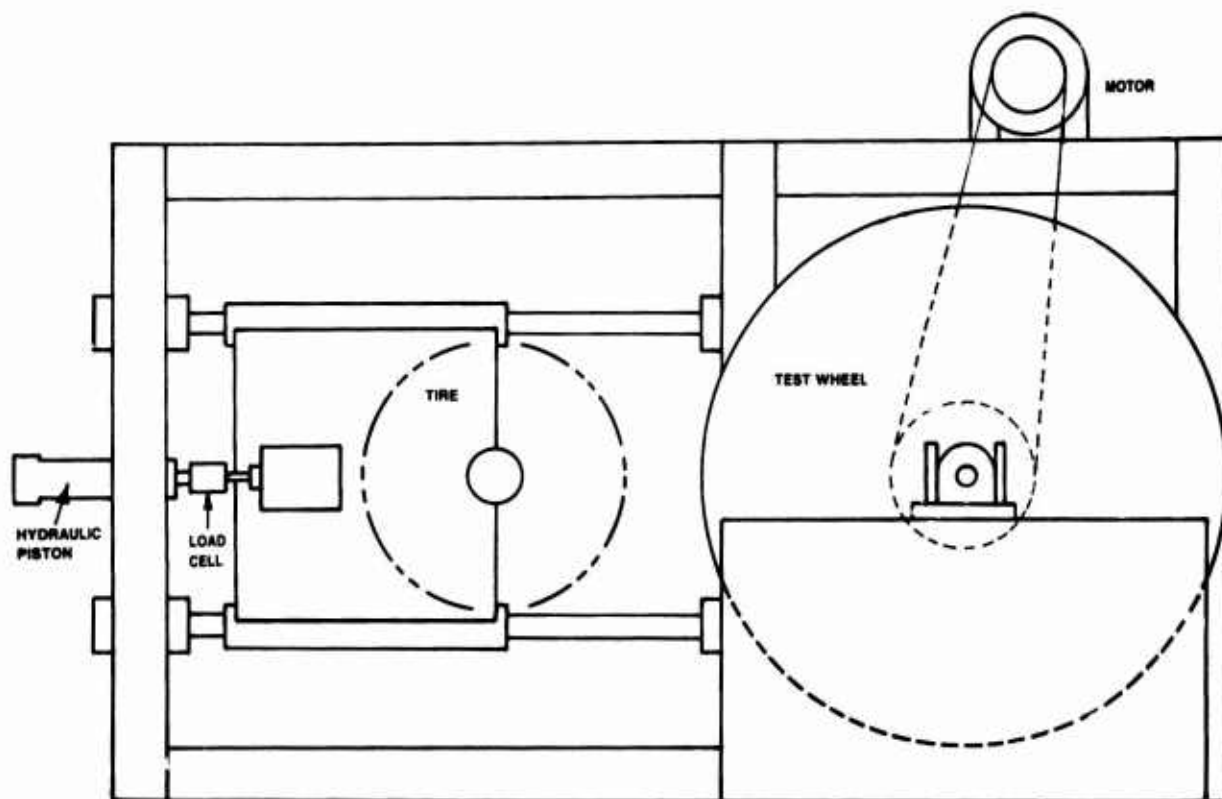DEAD WEIGHT LOADING SYSTEM, McNEIL CARRIAGE
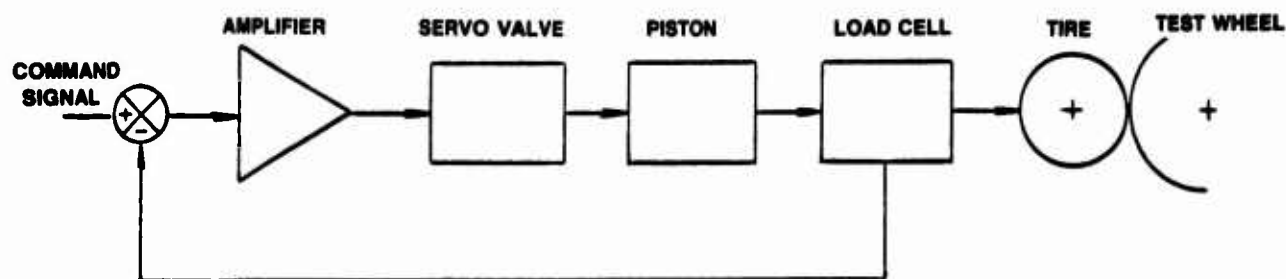

FIGURE 8

HYDRAULIC LOADING SYSTEM

FIGURE 9

SERVO CONTROL SYSTEM

which drives the servo valve. The servo valve controls the hydraulic fluid flow which in turn actuates a hydraulically operated piston. The piston drives the tire assembly against the roadwheel until the correct load, as sensed by a load cell, is reached. The load cell signal is compared to the command signal and if both are equal, the servo valve will maintain the required load. A change in command signal or load cell feedback signal will result in an error signal. This error signal causes the servo valve to correct the load until the error signal is reduced to zero. At that point, the system reaches a condition of equilibrium.

Feedback is necessary in any control system that must provide accuracy and response. Feedback is absolutely essential in any application using an electro hydraulic servo valve because of null bias present in all servo valves. We shall come back to this point in a later part of this paper when we compare the merits of electro hydraulic servo systems versus the merits of the system as described in this paper.

In order to correctly assess the part the loading system plays in the overall system of a tire endurance testing machine, an understanding of the FMVSS endurance test is essential. The following is a brief version of the D.O.T. 109 test.

FMVSS 109

Tires designed for highway use on passenger vehicles, trucks, buses, trailers and motorcycles are subject to testing in accordance with Federal Motor Vehicle Safety Standards (FMVSS 109 or FMVSS 119).

These standards require the determination of minimum tire performance levels when same are tested on smooth flywheels. Two tests are performed: Endurance (a step-up load test) and High Speed Performance (a step-up speed test).

Tests are conducted on 67.23" diameter smooth steel flywheels (one revolution of the flywheel gives 1/300 mile tire travel). The flywheels must be at least as wide as the tread of the tire under test. The ambient temperature should be $100^\circ F$.

The U.S. Dept of Transportation specifies the operating tolerances of the FMVSS test parameters as follows:

Tire Load in pounds	+0 to -40 lbs.
Tire Speed in MPH	+0 to - 2 MPH
Test Area, Temperature in $^\circ F$	± 5°
Tire Inflation Pressure	+2 to -0 PSI
Time (Cycles)	
4 hours +0 to - 2 minutes	
6 hours +0 to - 3 minutes	
24 hours +0 to -10 minutes	

It is further specified that the load reading in pounds must be made from load cells located directly on or adjacent to the test tire axle. Load cells located on the test tire carriage are acceptable provided the load recording indicates when the tire is actively engaged or disengaged from the test wheel.
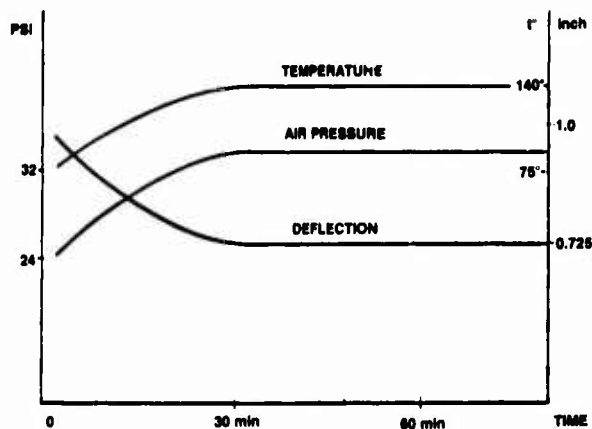
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FIGURE 10

TIRE PARAMETERS CHANGE
DURING ENDURANCE TEST

FIGURE 11

CONSTANT LOAD (SEE TEXT)

Immediately after running the tire the required time, the inflation pressure is measured. Tire pressure at the end of the test shall be no lower than starting pressure. After cooling the tire for one hour, it is removed from the test rim and visually inspected. After completion of the endurance test, the tire shall have no tread, sidewall, innerliner, ply, cord, or bead separation, chunking, broken cords, cracking or open splices. Thus far the FMVSS specifications.

It is interesting to note that the specified load regulation is given as a fixed maximum quantity by which the applied load may vary (+0 to -40 lbs). In terms of percentage load regulation, this means that at low load, the regulation can be as high as 4%, whereas at the high end of the tire load spectrum, regulation may have to be better than 1%.

A second point of interest is the determination of the tolerance limits, namely +0 lbs. and -40 lbs. This means that the applied load is not allowed to vary by any amount above the specified test load, but can vary by as much as 40 lbs. below that value. Closed loop systems, which of necessity have a ± excursion around the load set point cannot run the tire at the exact test load, but have to adjust the load to a value which is below the test load by a certain amount. This may not be detrimental at high loads, but will introduce a significant error at low loads. Thus, the D.O.T. specifications present a formidable problem to closed loop servo systems, which is not easily solved by conventional means.

The Behavior of the Tire During a Typical Endurance Test

In order to gain a better understanding of the design criteria for the construction of an automatic tire test loading system, one has to analyze the various factors which influence the perfo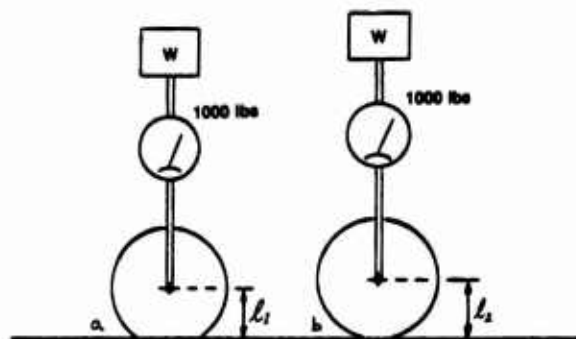rmance and accuracy of the system. One of the major factors the loading system has to contend with is the change of the tire's parameters during an endurance test.

Figure 10 shows typical temperature, pressure and deflection curves which were obtained with a tire loaded at T&RA load against a roadwheel at a rotational speed of 50 mph. The starting inflation was 24 psi. It is generally assumed that the following chain of events takes place: Due to the hysterestic losses in the tire materials, heat is generated. The air inside the tire cavity will reach a higher average temperature than at the beginning of the rolling process due to heat conduction, and this causes a higher pressure than the original inflation pressure of the tire due to the increased temperature of the trapped air. This pressure rise causes a reduction in tire deflection which in turn slows down the rate at which the temperature increases. In addition, the hysteresis characteristics of the visco-elastic tire materials also generally decrease with higher temperature. These interactions, while complicated, all tend to cause the deflection to decrease as time goes on, until equilibrium conditions are reached. At the point of thermal equilibrium, the rate of heat generated in the tire is equal to the rate of heat dissipated into the outside world through convection, conduction and radiation. From that point on, the deflection of the tire stays constant throughout the remainder of the endurance test, unless of course, the development of an abnormal condition in the tire changes the thermal equilibrium point.

Deflection and Load

The change in the tire deflection directly affects the test load, except in the case where the load is applied vertically to the tire and is not obstructed in its movement in the vertical plane. The following figures (11, 12) compare dif-
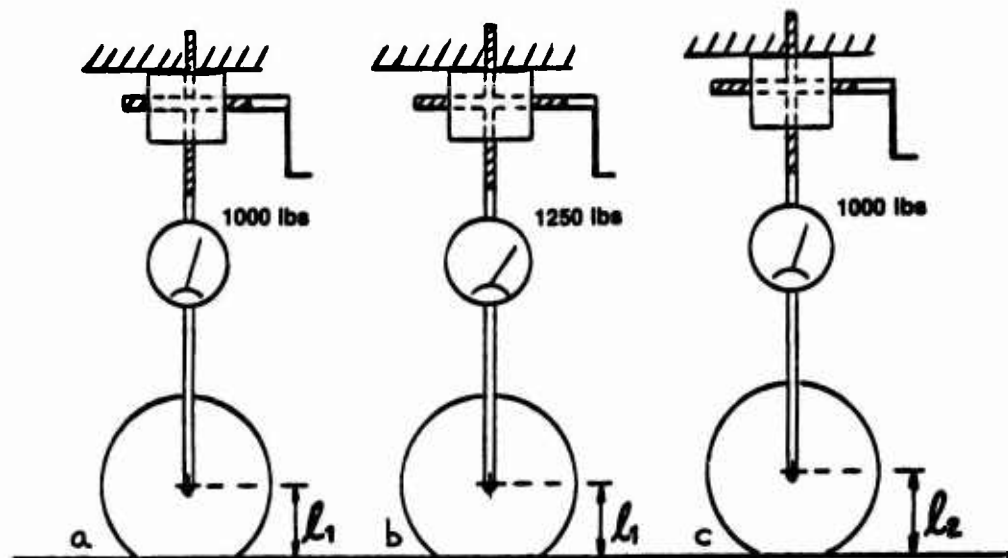
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FIGURE 12

a. COLD TIRE LOAD
b. TIRE LOAD AFTER WARMUP
c. RE-ADJUSTED LOAD

ferent methods of load application and their respective means to keep the load constant under varying tire deflections.

Figure 11 shows a vertical load applied to the tire. At the cold inflation pressure, the tire deflection caused the tire axle to be above ground by a distance ℓ_1. After warmup, (Figure 11b), the deflection decreased with the result that the tire axle moved up assuming a new distance of ℓ_2 above ground. The weight (load) on the tire moved up by the same amount and obviously did not change its value. Under those conditions, the load stays constant and is not affected by changes in tire deflection.

Let us now again apply the load vertically, but instead of a weight we shall use a screw type loading system. (Figure 12)

The load is adjusted to 1000 lbs. by turning the screw until the load indicator shows that amount. Inflation pressure is 24 psi (cold) and axle height is ℓ_1. After warmup, the increased inflation pressure (32 psi) appears as an addition to the 1000 lbs. force and the tire experiences a resultant load of 1,250 lbs. (Figure 12b)

In order to return to the original test load, the screw is backed up until the load indicator shows 1000 lbs. Measurement of the axle height now shows ℓ_2 (Figure 12c) which is the same distance as shown in Figure 11b for a warmed up tire under non-restricted load conditions.

The principle just described applies to any type of loading system, and either manual or automatic load regulation has to be performed in order to compensate for the increase in tire inflation pressure during the warmup period.

In the case of dead-weight systems, as for instance the government machine, the decrease in tire deflection causes carriage (D) to move toward lever BC. (See Figure 5) This causes levers BC and AB to move out of the balance position with the result that the tire test load has now changed from the required value to an incorrect value. To rebalance the system, the distance between the carriage D and the lever BC has to be decreased by an amount equal to the change in deflection. In practice, this is accomplished by turning levelling screw E until lever AB is again levelled.

In the case of electro-hydraulic servo systems (See Figure 9) it is the load cell which senses an increase in test load because of an increase in inflation pressure. An error signal is thus created and a command is given to the piston to back up until the load cell again senses the required test load.

Load Regulation

Armed with an understanding of the interaction between tire inflation pressure and test load, we shall now proceed to analyze the performance of the load regulation system during a typical tire endurance test.

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Figure 13 shows test load deviations from the nominal test load taken over a major part of the endurance test period. The test load graph is typical of dead weight loading systems where the adjustment is performed manually.

A typical test sequence is as follows:

The test starts with the tire under the correct T&RA load. Within minutes, the tire begins to warm up which is reflected in an imbalance of the loading system. The first adjustment is performed at approximately 15 minutes after the start of test, bringing the test load back to normal. The tire continues to warm up, and another adjustment is performed. Typically, after 45 minutes, the tire has reached a thermal equilibrium state. Another adjustment is made and from that point on inflation pressure stays constant. Consequently, there is no further need for additional adjustment of the test load for the remainder of the test.

Automatic loading systems perform the regulation in precisely the same way. Figure 14 shows the relationship between tire inflation, piston travel and regulated test load. The curves are typical for any hydraulic servo loading system. The piston is backing up, compensating for increasing load, thus keeping the test load constant throughout the test.

The oscillatory waveform of the test load and piston travel curves is the result of the hydraulic servo valve action. In an ideal valve, the controlled oil flow is directly proportional to the error signal, so that at zero error, control flow is zero. In a real valve, such is not the case. A slight error signal so-called null bias is required to bring the valve to null. This action of the servo causes a continuous flow of

oil into and out of the loading cylinder, with the result that the loading system is never at rest during the entire endurance test.

Be this as it may, the basic performance of any of these loading systems is the same and is governed by the following two criteria:

1. Tire load increases because of increase in inflation pressure.

2. Tire load stays constant at thermal equilibrium.

This leads to the following important conclusions:

1. Load regulation has to occur in one direction only (decrease load).

2. Load regulation is not necessary after thermal equilibrium has been reached.

These conclusions in conjunction with D.O.T. specifications provided the basis for establishing the minimum necessary requirements which had to be met by a tire loading system. Namely:

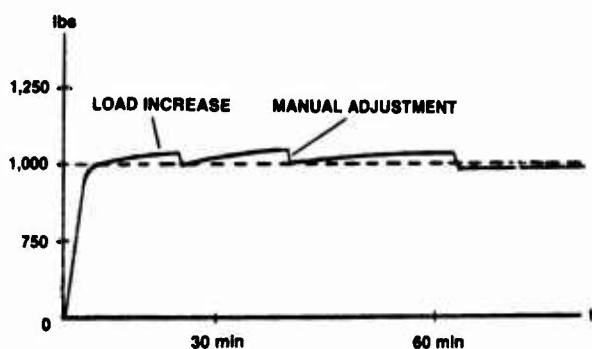|		
1.	LOAD RANGE	300 lbs. to 3000 lbs.
2.	LOAD ACCURACY	+0 to -40 lbs. at any setting
3.	LOAD REGULATION	Uni-directional
4.	DUTY CYCLE	System to be operative only when regulation is required.

FIGURE 13
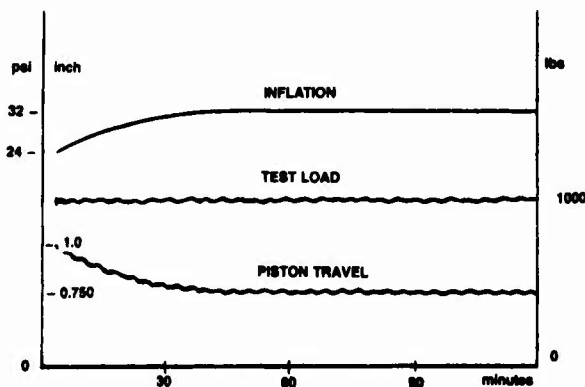TYPICAL TEST LOAD CURVE WITH
DEAD WEIGHT LOADING SYSTEMS

FIGURE 14
TYPICAL TEST LOAD CURVES WITH
AUTOMATIC LOADING SYSTEMS

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5. LOAD CHANGE — Automatic and programmable

6. CONSTRUCTION — Rugged and simple

The rationale for these six requirements is as follows:

1. LOAD RANGE

The load range depends on the type of tires to be tested. The load range of 300 lbs. to 3000 lbs. is for passenger car tires.

2. LOAD ACCURACY

The degree of accuracy needed in keeping the required test load is based on D.O.T. specifications.

3. LOAD REGULATION

Analysis revealed that regulation is required in one direction only. That is, during the early part of the test, the load on the tire is continuously diminished in order to compensate for increase in tire pressure. It should be mentioned at this point that uni-directional regulation will always occur under normal operating conditions, provided that ambient temperature and speed remain constant and no air loss occurs in the tire. Under varying operating conditions, thermal equilibrium will change and may cause an increase or decrease in inflation pressure and/or test load. However, abnormal conditions a priori mean that the test should be truncated since it does not conform to D.O.T. specifications.

4. DUTY CYCLE

The system performing the load regulation should be active only when called for. This is advisable for any servo regulation system but more so for a tire endurance test regulation system since it has been shown that the major part of the test does not require regulation at all. In other words, energy should be expanded by the system only when regulation is performed.

5. LOAD CHANGE

FMVSS 109 and 119 call for a number of load changes during the SUL (stepped up load) cycle. The system should be capable of automatically stepping up the load to a pre-programmed new test load value when so desired.

6. CONSTRUCTION

Construction has to be simple and rugged. Tire endurance tests are performed under severe and adverse conditions. The employment of delicate control units and instruments should be avoided. Operation must be reliable and virtually maintenance free.

Evaluation

Having thus established the minimum absolute requirements for an automatic tire loading system, we shall now proceed to evaluate existing loading systems in the light of these criteria. The results are tabulated in Chart I.

EVALUATION OF COMMERCIAL LOADING SYSTEMS							
TYPE OF LOADING	METHOD	REGU-LATION	ADJUST-MENT	POWER REQUIRED	RELIA-BILITY	ADVANTAGE	DISADVANTAGE
DEAD WEIGHT	WEIGHTS LEVERS	± 5 lbs	MANUAL	NONE (GRAVITY)	EXCELLENT	MINIMAL MAINTENANCE	MANUAL ADJUSTMENT, BULKY, NON-PROGRAMABLE, NO LOAD READOUT
PISTON THRUST	CLOSED LOOP HYDRAULIC SERVO SYSTEM	± 10 lbs	AUTOMATIC	POWER CONSUMED DURING ENTIRE TEST	POOR	EASE OF OPERATION, PROGRAMABLE, LOAD READOUT	EXCESSIVE BRKDWN MAINT. PROBLEMS, CONTINUOUS WEAR-TEAR, NOISE POLLUTION
MECHANICAL SCREW	CLOSED LOOP SERVO CONTROLLED DRIVEN SCREW	± 20 lbs	AUTOMATIC	POWER CONSUMED DURING 90% of TEST TIME	FAIR	EASE OF OPERATION, PROGRAMABLE, LOAD READOUT	DEAD ZONE PROBLEMS, HUNTING, CONTINUOUS WEAR-TEAR

TABLE I

Design Guide Lines

The information thus far presented, inevitably led to the following conclusions and design guide lines.

1. Since there is no need for load regulation in both directions, there is no need for sophisticated hydraulic servo systems. This eliminates in one fell swoop severe maintenance problems caused by continuous wear and tear on pistons delicate servo valves, contamination of hydraulic oil, leakage, etc., etc.

2. Uni-directional load regulation also eliminates the need for closed loop servo controls as used with motor driven screw type systems. Although these systems are designed to stop the screw action within a certain "dead zone", thus improving efficiency, it turned out that the electrical adjustment of the dead zone was very critical, resulting in an unreliable regulation.

3. Automatic load control is superior to dead weight loading. It eliminates the need for heavy weights to be manipulated by the operator.

As dictated by the design guide lines and conclusions, the final design resulted in a straight forward, simple, loading system which is operated by the following:

1. Motor driven screw type loading.

2. Uni-directional automatic load regulation.

3. Programmable load change control.

The heart of the system is a directional control unit which sees to it that regulation takes place in one direction only. Moreover, this unit also assures that regulation occurs only when called for, thus providing a highly efficient system.

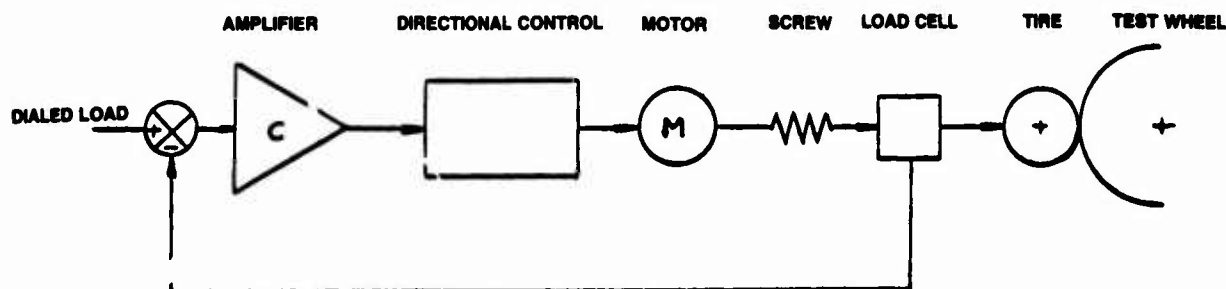Figure 15 shows an operational flow diagram of the system.

The required load is dialed in and appears as an analog voltage at comparator C. The load cell which is mounted in line with the loading screw supplies the analog tire load signal which is to be compared with the dialed-in load in comparator C. As long as these two signals are not equal, comparator C provides an output signal which is amplified and passed through the directional control to motor M. The loading screw, driven by motor M, will move the tire against the roadwheel until tire load equals dialed-in load. Bypassing the directional control makes the just described control system look exactly like a typical closed loop servo system. It is the introduction of the directional control which changes the universal closed loop servo system to a system which is optimized for the task at hand, namely, regulating the load for tire endurance testing purposes.

Action of the directional control is best explained with the aid of Figure 16.

Let us assume that a test load of 1000 lbs. is required and has been dialed-in. Initially, the directional control has set the motor rotation into the clockwise mode, thus driving the loading screw forward with the result that the tire is being loaded. When the tire load equals 1000 lbs., the comparator output equals zero. This zero crossing signal is used to cause the directional control to reverse the rotation of the motor and to stay in that mode for the remainder of the test. As the tire warms up, the test load increases, causing an error signal. As explained previously, this signal causes the motor to operate and turn the screw in a counter clockwise direction until the test load again equals the dialed-in load.

There is a slight overshoot because of inertia in the system causing the regulated load to settle at approximately 5 lbs. below the set point. The tire continues to warm up and the test load again crosses the dialed-in load level, causing another cycle of load regulation. These cycles continue until thermal equilibrium is reached at which point no further regulation is required.

FIGURE 15

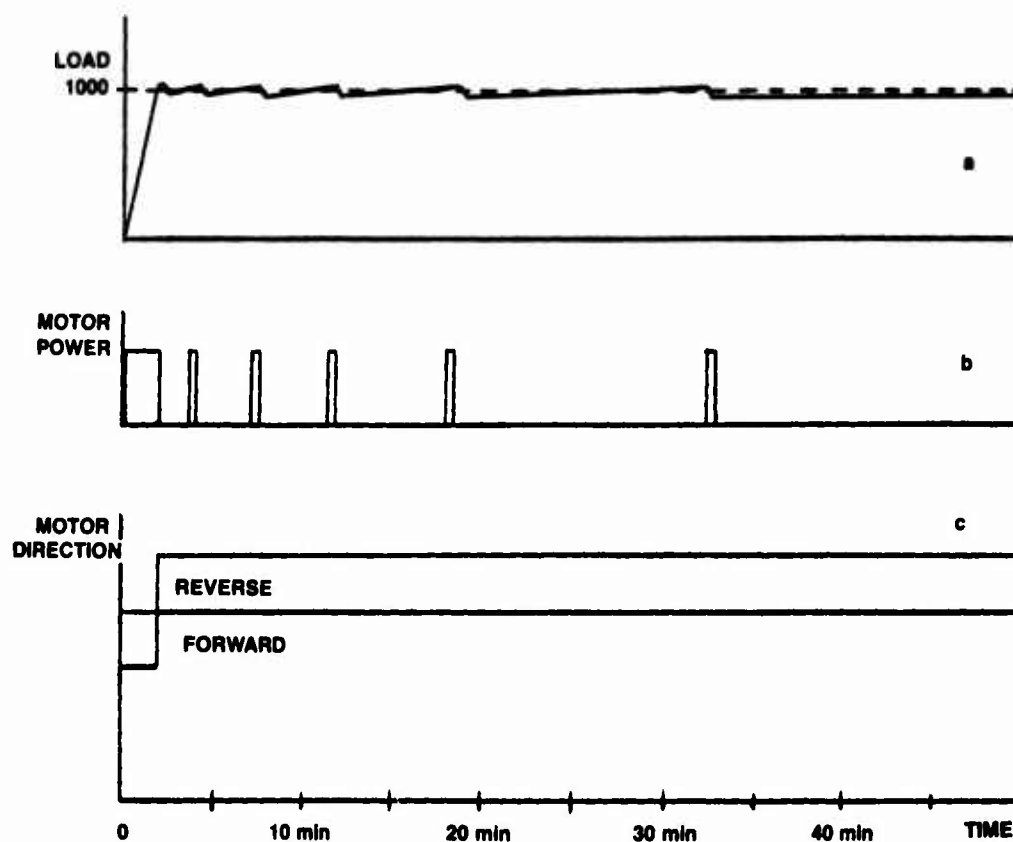OPERATIONAL FLOW DIAGRAM (SEE TEXT)

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FIGURE 16

TYPICAL REGULATION PATTERN WITH
UNI-DIRECTIONAL LOAD CONTROL (SEE TEXT)

The remarkable reduction in motor power consumption is shown in Figure 16c. The motor is required to operate only when the test load exceeds the predetermined level, and then only for the short time needed for backing up the screw. In between these points, the motor is shut off completely. Since most of the test is conducted in an equilibrium state, the motor and associated mechanical members are hardly used, resulting in an excellent reliability of the system. It is, of course, the introduction of the directional control, which, by allowing load regulation in one direction only, enabled the design of a reliable and rugged loading system. And this, we believe, would not have been possible without a detailed analysis of the endurance test as presented in this paper.

Although not originally intended, the uni-directional method yielded two additional important features:

1. Detection of change in test conditions as caused by air loss, ambient temperature, roadwheel speed, etc.

2. Detection of the onset of incipient failure, which enables a truncation of the test before tire destruction.

A discussion of these features will follow the next chapter which describes the electronic circuitry of the loading system.

Electronic Control Circuits

A functional block-diagram of the electronic portion of the loading system is presented in Figure 17. The design is straight forward and utilizes off the shelf items such as signal conditioners, motor control units, etc.

Figure 18 shows a diagram of the complete circuit. Load regulation, load programming, incipient failure and abnormal condition detection are all accomplished with the aid of three op-amps, a few transistors and five relays. It is not the intent of this paper to give a detailed description
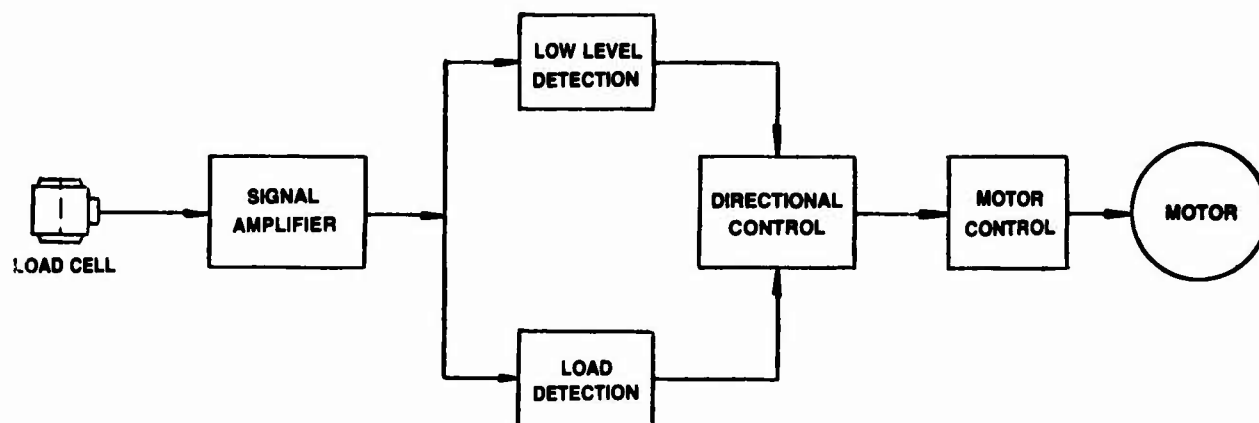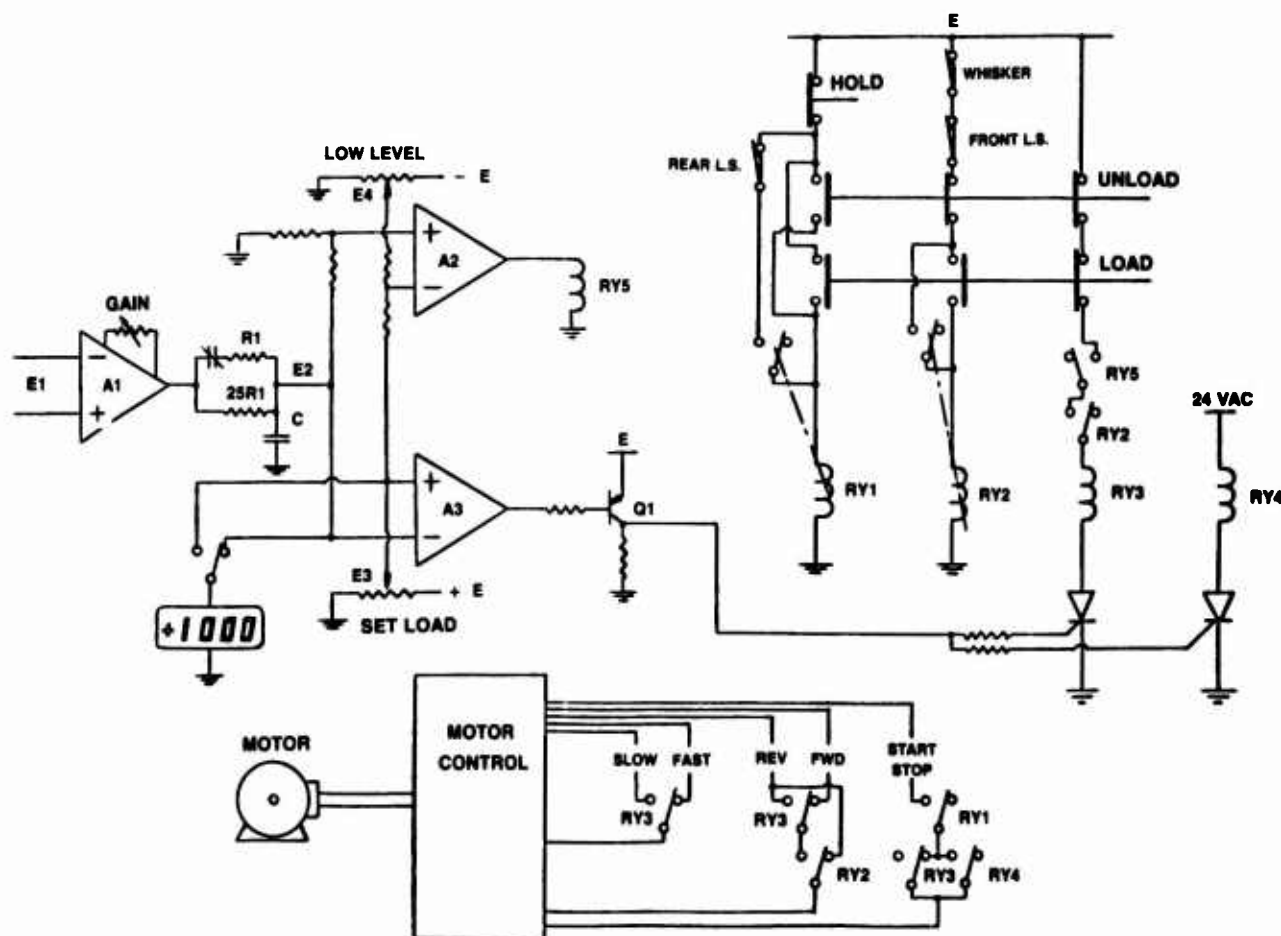
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FIGURE 17
FUNCTIONAL BLOCK DIAGRAM

FIGURE 18
ELECTRONIC DIAGRAM OF UNI-DIRECTIONAL CONTROL

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of the circuit. However, some explanation is necessary in order to understand the detection features.

The output signal of the load-cell (which senses the applied test load) is amplified in a special instrumentation amplifier A_1. The gain is adjusted to provide 1mV per 1 lb. load. The amplified signal is filtered (force variations are removed) and is then applied to the input of amplifiers A_2 and A_3. Amplifier A_3 compares the load cell signal with an analog load setting signal E_3. When the load cell signal exceeds the set load E_3, amplifier A_3 changes its output polarity and causes relays RY_3 and RY_4 to pull in. Relay RY_3 is the previously described uni-directional control. Its function is to change the direction of the screw loading motor into the reverse mode and slow down the rotational speed of same. The relay will stay locked for the remainder of the endurance test, thus keeping the motor in the reverse mode and allowing only backup motion of the screw if regulation is required. Relay RY_4 will turn the motor off when the screw has backed up sufficiently to return the load cell signal to just below the set load signal.

Monitoring the action of Relay RY_4 provides an excellent record of the tire's behavior during the test. Analysis of the frequency at which RY_4 is operating provides the basis for the incipient failure detection. Operational amplifier A_2 is used to detect an excessive decrease in test load, that is more than the allowable -40 lbs. as specified by D.O.T. The amplifier is wired up as a voltage comparator, the voltages being the analog test load voltage (E_2) and a voltage produced by subtracting a constant voltage (E_4) equivalent to 40 lbs. from the dialed in test load (E_3). When the test load voltage E_2 falls below this low level (E_3-E_4) the amplifier changes polarity and activates relay RY_5. The action of relay RY_5 is used in two ways. It signals the operator that a change in test conditions has taken place and, if so desired, causes the screw loading motor to change direction and drive the tire towards the test wheel until the correct test load has been obtained. At this point, the uni-directional Relay RY_3 takes over and operation reverts back to normal as previously described.

The remainder of the circuit diagram as depicted in Figure 18 contains the digital read-out, various safety limit switches, the motor control unit, and the motor. The "fail-safe" approach was used wherever possible, that is, loading the tire against the roadwheel can occur only with relays in the energized state and limit siwtches in the normally closed position.

Incipient Failure Detection

It has been shown in the literature and elsewhere (4, 5) that the majority of developing tire flaws are accompanied by an increase in tire temperature. In fact, this phenomenon
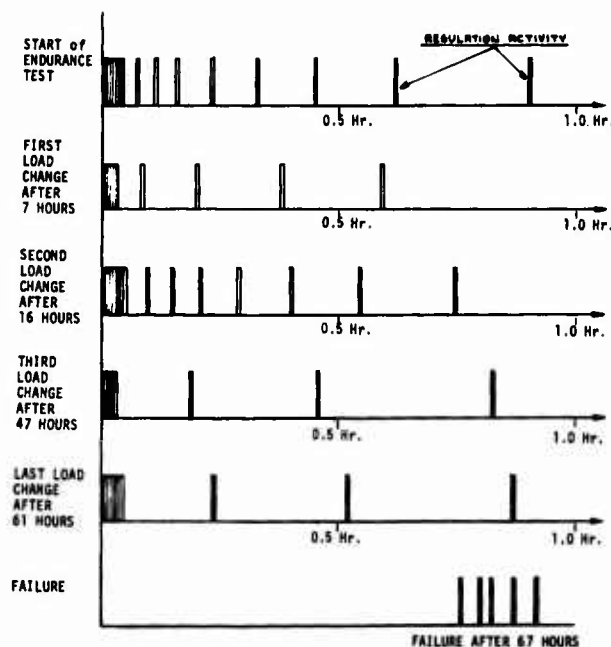

FIGURE 19

INCIPIENT FAILURE DETECTION THROUGH OBSERVATION OF LOAD REGULATION ACTIVITY

served as the basis for the development of the Monsanto TFD system (6). An increase in tire temperature causes an increase in tire pressure with the result that relay RY_4 is energized in order to initiate load control action. Figure 19 shows copy of an actual recording of RY_4's activity during an entire endurance test with stepped load changes. Activity is very pronounced during the first 10 minutes of the start of the test and for the same period of time after the start of the endurance test. As can be seen on the last part of the recording, relay RY_4 began to show activity very close to the point where the test terminated. Termination in this case was caused by destruction of the tire.

A sizeable number of endurance tests were performed and records of relay activity obtained. In almost all cases relay activity started with incipient failure and continued towards the point of destruction of the tire. Based on these findings, a number of endurance tests were terminated when increased relay activity pointed out the possible development of tire failure. Subsequent analysis confirmed that indeed incipient failures were present in those tires. The method thus provides a means for studying the propagation of the incipient failure in far greater detail than would have been possible under normal testing where the destruction of the tire in many cases masks the starting point.

Detection of Change in Test Conditions

As has been pointed out, thermal equilibrium in the rolling loaded tire will be obtained under normal conditions, namely, controlled ambient temperature, constant test wheel speed and no air loss in the tire during the test. Any change in these conditions will manifest itself in a change of the test load. In general, ambient temperature and rotational speed of the test wheel are well controlled and do not present a serious problem. Air loss, however, is a common occurrence, and the test must be terminated if air leakage has been established. Since test load is directly proportional to tire air pressure, a decrease in air pressure will result in a decrease of test load.

The uni-directional method of the loading system prevents load regulation during a decrease in load. This feature made possible the detection of air loss by simply monitoring the progression of a decrease in test load and trigger an alarm when the test load has reached a pre-determined low value. In practice this has worked out very well. The alarm system has aided in terminating tests where tires developed slow air leakage. With regular closed loop hydraulic servo systems, this detection would not be possible, thus causing many hours of wasted test time.

In Summary

A description of a unique loading and control system for tire endurance testing machines was presented. Analysis of tire behavior during endurance tests led to a non-conventional approach in designing a system which, being simple and rugged practically eliminates downtime and maintenance problems. Versatility of the system is further enhanced through the addition of electronic circuits which detect incipient tire failures and abnormal test conditions. Provision has been made to truncate the test at the onset of incipient tire failure. Massive failure is thus prevented, enabling a detailed analysis of the cause of failure and its progression.

ACKNOWLEDGMENTS

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LABORATORY MEASUREMENT OF PASSENGER CAR TIRE TREAD WEAR

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ABSTRACT

One-thousand mile wear tests were conducted on Calspan's Tire Research Facility using preselected G78-15 and GR78-15 tires representative of low mileage and high-mileage specimens. A tire test schedule was devised that achieved (a) tread surface textures similar to road-worn tires, (b) uniform cross-tread wear and (c) predictable wear rates. Tire wear was measured using sensitive electro-mechanical tread-depth sensors. The test data verified the ability of the laboratory method to rank order the test specimens in accord with their selected basis as low- and high- mileage tires. Operational experience is noted and recommendations for technique improvement are proposed.

TIRE TREAD LIFE ranks among the important factors that determine tire quality since it involves considerations of safety and operating cost. Attesting to the importance of tread life is the proposed Uniform Tire Quality Grading Standard of the National Highway Safety Administration which includes a provision for tread wear grading of new tires.

A direct approach to determining tire tread wear rates is to conduct vehicle mileage accumulation tests over regular highways or special test courses. Despite its apparently compelling simplicity, this approach has some serious drawbacks. In outdoor testing many important parameters that affect tread wear are not subject to control. As a result, high mileages must be accumulated on the test specimens in an attempt to minimize distortions in test data from these sources. Such lengthy tests are very expensive and attempts have been made to shorten them by artificially increasing the wear rate. Unfortunately, such expedients have not proved to be very useful since wear rates measured among tires tested under both normal and accelerated wear conditions cannot be relied upon to correlate.

As an alternative to the vagaries and expense of road tests a laboratory method has been developed at the Calspan Tire Research Facility (TIRF) (1)* that provides a reasonably short, reproducible and economical test procedure for the production and measurement of tire tread wear. Successful implementation of the laboratory method has required realistic simulation of tire wear processes occurring in normal use. In addition, the need to measure accurately tread-depth changes of the order of one mil has had to be satisfied.

The initial experimental tread wear studies were sponsored by the U.S. Army Tank-Automotive Development Center (TACOM) (2). Test results obtained from this program demonstrated the feasibility of conducting meaningful tread-wear tests on TIRF albeit only one size and one type (tread design) of tire was employed in that study.

The subsequent program devoted to tread wear studies was conducted for the Rubber Manufacturers Association (RMA) and involved a variety of passenger car tires (3). These tires were pre-selected as having high-mileage or low-mileage wear characteristics and the principal objective was to demonstrate the capability of the laboratory tests to properly rank order these tires.

The RMA study forms the basis for this paper which describes the laboratory test procedures which were developed to achieve tire wear characteristics similar to those experienced in normal highway usage and the implementation of a technique using electro-mechanical displacement transducers to measure tread depth. Test data are presented and their significance is discussed. Operational experience is described and recommendations are suggested for further improvements to the technique.

BACKGROUND

The many difficulties which are inherent in outdoor tests designed to measure tire tread wear are well documented (4). Because it does provide a "real life" environment and since practical alternatives have not been available heretofore, the practice of road testing continues to be used. A brief summary of the pros and cons of road tests is given in Table I.

In contrast, laboratory tests provide a controlled environment, a controlled variation of tire service parameters, the feasibility of shorter tests and the direct evaluation of the relationship between service parameters and tire wear. Calspan's computer-controlled TIRF machine, Figure 1,

*Numbers in parentheses designate References at end of paper.

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Table I - Road Testing of Tire Tread Wear

ADVANTAGES:

● Tests duplicate "real-life" wear conditions.
● There exists user familiarity with the test procedure.

DISADVANTAGES:

● Uncontrolled tests result in extremely large data spread.
● Tests are of long duration at normal wear rates.
● Tests are costly.
● Data are biased by vehicle factors.
● Data are characterized by a high "noise" level because of such uncontrollable influences as weather conditions, road temperature, driver inputs, etc.

is ideally suited to the conduct of indoor testing of tire tread wear. It provides a high-speed flat roadway, a six component metric balance and is capable of generating a wide range of wear cycles under precise servo control of slip angle, torque, load and speed. In addition, a choice of roadway surfaces is available. To exploit the potential of the TIRF machine, it was necessary to develop an efficient test methodology to (a) duplicate the characteristics of road-worn tires and (b) produce a wear level of normal severity. Concomitant with these needs was the requirement for a precise and accurate means of measuring tread loss.

Table II summarizes the more important aims.

Table II - Objectives of TIRF Tread Wear Testing

● Development of a "normal severity" wear cycle (10-20 mils/kilomile).
● Demonstrated feasibility of low-mileage wear tests (1600 km or 1000 miles).
● Demonstrated wear levels of 10 to 20 mils per kilomile.
● Development/implementation of a tread-loss measuring technique accurate to 0.1 mil.
● Demonstrated correlation with road test results.

Longer range objectives include the evaluation of the dependence of tread wear on speed, load, inflation pressure and tread depth.

The initial effort towards a partial fulfillment of the objectives listed in Table II took place under TACOM

sponsorship and is reported upon in detail in Reference 2. A more ambitious program using passenger car tires was undertaken for the RMA and included more explicit objectives which are detailed in the succeeding section. A complete summary of the RMA study is given in Reference 3.

TEST PROGRAM

The principal objective of the RMA test program was to demonstrate the capability of TIRF wear tests to rank order tires on the basis of tread wear. Tire test specimens were selected whose relative tread life characteristics were known. These included high-mileage radial tires (GR78-15), control bias-ply tires (G78-15) and low-mileage bias-ply tires (G78-15).

Subordinate objectives included the generation of uniform cross-tread wear, tread surface textures representative of road-worn tires and achievement of specified wear rates. Improvements in tread-wear measuring instrumentation and measurement procedures were implicit requirements in the fulfillment of these goals.
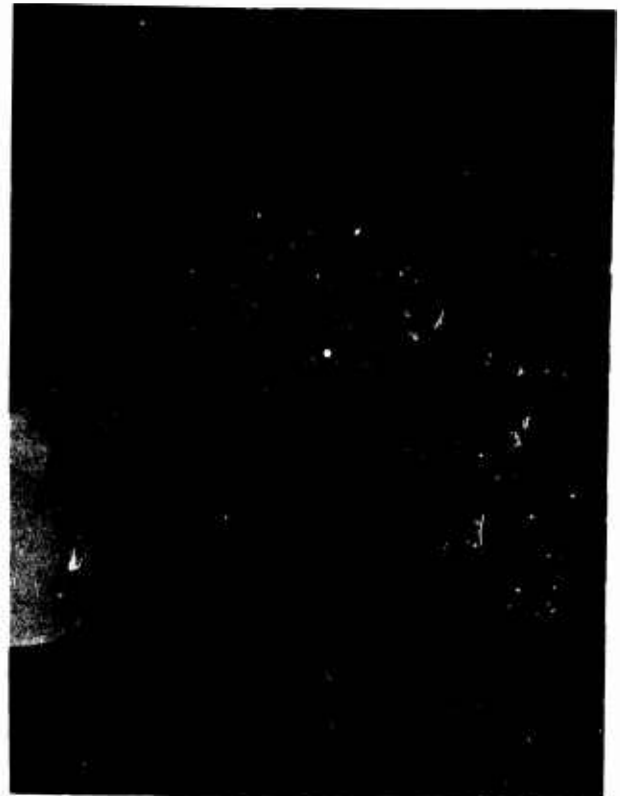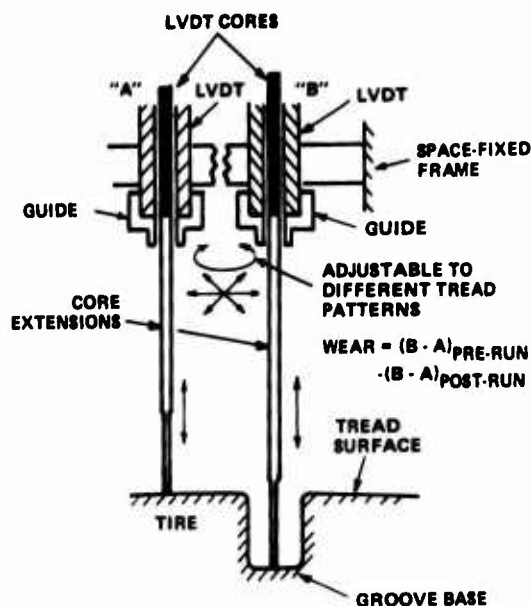

FIGURE 1 TIRF MACHINE

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FIGURE 2

GEOMETRY OF LVDT WEAR
MEASURING DEVICE

All tires had been pre-conditioned by operation on vehicles for 1600 miles. Tests were conducted at a load equal to 85% of the T & RA rated load at 24 psi inflation pressure and at a speed of 80 mph for a distance of 1000 miles. The relatively high speed reduced the machine operating time to 12½ hours. Tire tread surface temperatures were monitored continuously to insure that they did not exceed those experienced during typical road tests ($\leq 200^{\circ}F$). Replicate tests were performed on one high-mileage radial tire to ascertain repeatability of the wear data.

Roadway surface samples, Safety-Walk made by the 3M Company, were examined at intervals during the tests for rubber contamination and wear as all testing was deliberately constrained to one path on the TIRF belt surface. A scanning electron microscope (SEM) was used for sample analysis.

TREAD WEAR INSTRUMENTATION

A. Description

Tire tread wear rate was determined by the average change in tread depth which was measured after 1000 miles of the test cycle was completed on the tire. This measurement was made using an electromechanical transducer sensitive to linear displacements. Commonly known as a linear variable differential transformer (LVDT), this device, using auxiliary

electronics, provides a d-c electrical signal that is directly proportional in magnitude to the imposed displacement. Direction of displacement, relative to a null reference, is indicated by the polarity of the output signal.

Calibration tests of the LVDT probes have demonstrated excellent linearity and stability. Using gage blocks to introduce known displacements, LVDT's having a range of ±0.5 inch, produced data with a standard deviation of less than 0.1 mil. Thus, 68% of all measurements would be expected to have a random error not exceeding one-tenth mil.

LVDT probes are used in pairs to perform tread-depth measurements with one probe in contact with the tread surface (rib) and the other in contact with the base of an adjacent groove. All measurements are made relative to a common reference external to the tire. Figure 2 illustrates the geometry of this device. Local tread loss is determined by taking a second set of measurements, following a wear test, with the probes set *exactly* at the same surface positions on the tire.

Wear measurements are facilitated using a frame structure that incorporates a horizontal spindle shaft to mount the tire/rim assembly and permit rotational positioning. The base assembly supports a fixture, above the tire, on which are mounted two pairs of LVDT probes and allows a gross positioning of the probes relative to the tire tread surface. Each pair of probes is mounted in a smaller fixture that permits (1) variation in the relative spacing between probes, (2) rotational adjustment of the entire dual-probe assembly and (3) vertical positioning of the probe-core assemblies. A general view of the apparatus is shown in Figure 3 while a

FIGURE 3

LVDT MECHANICAL PROBES
IN CONTACT WITH TIRE

close-up picture of the core-probe assemblies in contact with a tire is shown in Figure 4. The advantage of using two pairs of probes is that simultaneous measurements can be made across the tread and along two meridians (by rotating the tire).

Electrical signals from each individual probe are fed directly into the TIRF computer where the necessary computations are made to arrive at a mean wear value based on all of the measurements. Computer printouts tabulate: (1) prerun and postrun tread depths at each location sampled, (2) tread depth changes, i.e. tread loss, at each location sampled and (3) the average wear.

B.   Wear Measurement Locations on the Tire

Use of mechanical sensors to measure tread wear necessitates that pretest and post-test tread depth data be taken at precisely the same points on the tire surface. These fiducial points must be established on the tire surface and not with regard to an external (spatial) reference because of the viscoelastic properties of the tire. The following technique was used to assure correspondence between probing points in pretest and post-test measurements.

A small dot of color (made with a rubber-marking crayon) was located on the flat area of a groove base and one probe rod of the LVDT sensor was centered upon it. The other probe of the pair was then adjusted laterally/rotationally to contact a suitable point on the surface of a contiguous rib. For rib-type passenger car tires, interprobe spacing was typically 5/8 to 1 inch. The probe fixture permitted precise measurement of the angular and linear dispositions between these probes, relative to the fiducial dot, so that they could be exactly reproduced for repeat measurements.

Forty-eight measurements of tread depth were made on each tire for each test. This total was comprised of measurements made at each of six circumferential stations, approximately equally spaced, on each of four tire meridians and a complete set of replicate measurements made as the tire was rotated through one revolution. Shoulder areas of the tread were avoided in selecting wear locations as were rib edges subject to possible feathering. Figure 5 illustrates a tire footprint with the selected wear locations noted thereon.

Specific procedures employed in wear measurement are detailed below. First the tire tread surface was thoroughly cleaned, the tire was inflated to 24 psi and mounted in the test apparatus which was located in a temperature/humidity controlled area. Following tire temperature equilibration, wear locations were selected and marked in the manner described. The wear instrumentation was calibrated using a special fixture and tread depth measurements were made immediately at the 24 selected wear locations. The tire was

FIGURE 4

LVDT MECHANICAL PROBES
IN CONTACT WITH TIRE

thereupon subjected to the wear cycle on the TIRF machine. Following completion of the wear test, the tire was reinstalled on the test apparatus and a minimum test period of four hours was allotted to eliminate tire creep, flat spotting and thermal gradients. The tire tread surface was again thoroughly cleaned using a bristle brush and an air flush. Tire pressure was checked to verify that there had been no loss of air. A second set of tread depth measurements was then made and the data were reduced to determine the mean tread loss during the test.

To quantitatively ascertain measurement repeatability with the tread depth sensors, tests were made at each of three conditions representing independent sources of random error: (a) the calibration of the sensors using gage blocks to provide known displacements, (b) tread depth measurements, at a given location on a tire, following a loosening/tightening of the rim on the test fixture studs and (c) tread depth measurements, at a given location on the tire, with the wheel turned through one revolution between successive measurements. Sample standard deviations (s), as determined from these tests are shown in Table III.
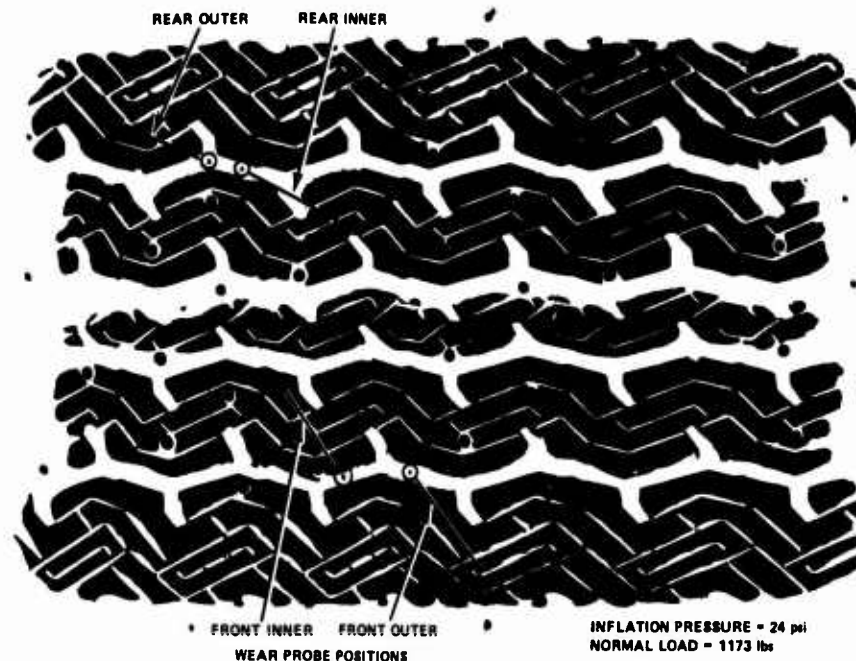
FIGURE 5 FOOTPRINT — DUNLOP HIGH MILEAGE RADIAL — #7-1-48

INFLATION PRESSURE = 24 psi
NORMAL LOAD = 1173 lbs

REAR OUTER REAR INNER

FRONT INNER FRONT OUTER
WEAR PROBE POSITIONS

Table III - Repeatability of Wear Probe Measurements

Error Source	Wear Probe A	Wear Probe B
Calibration		
(gage blocks)	s=0.07 mil	s=0.085 mil
Loosened studs	s=0.82 mil	s=0.64 mil
Tire rotation	s=0.21 mil	s=0.31 mil
Composite	s=0.85 mil	s=0.72 mil

The largest random error was associated with loosening of the rim studs. A composite standard deviation for each probe was calculated as the root of the sum of the squares of each of the three error components.

WEAR TEST DETAILS

Tread wear is a strong function of slip as produced by applied steering angle and/or wheel torque. Several levels of wear severity are recognized and are expressed in Table IV in terms of mils per kilomile. In developing test procedures to achieve low-to-moderate wear rates, uniform cross-tread wear and surface textures representative of vehicle-worn tires, use was made of information developed on the TACOM program (2) related to the frequency distribution of slip angle and longitudinal slip, generated by passenger

vehicles in typical urban/suburban/highway operation. From this information, it was judged that slip angles should not exceed 2^0 and longitudinal slip should not exceed 2½% if typical wear rates are to be achieved. Details pertinent to the selection of these limiting values are presented in Reference 5 and will not be discussed here.

Using one control tire and one high-mileage radial tire as test specimens, various cycles and random schedules of slip angle and torque were explored in order to define an acceptable wear schedule (i.e. one that met the stated objectives of wear rate and tread surface characteristics). All tests were made at a speed of 80 mph, a normal load of 1170 lbs., zero camber angle and a distance of 200 miles. Wear measurements were made after each 200-mile test segment. Mileage during this exploratory phase totaled 1800 miles (on both tires). As the result of these tests,

Table IV - Tread Wear Severity *

Low wear <10 mil/kmi (straight run)
Moderate wear 10-25 mil/kmi (0.2g cornering)
Severe wear 25-50 mil/kmi (0.3g cornering)
Very severe wear >50 mil/kmi (>0.3g cornering)

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* Applicable principally to passenger car tires.

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Table V - Tire Identification Schedule

TIRF Tire No.	Manufacturer	Size	Kind of Tire	Other Identification
7-1-48*	Dunlop	GR78-15	Radial (High-Mileage)	Elite Steel Radial
8-1-48	Dunlop	GR78-15	Radial (High-Mileage)	Elite Steel Radial
9-1-48	Dunlop	GR78-15	Radial (High-Mileage)	Elite Steel Radial
11-1-48	Armstrong	G78-15	Bias	4-Ply Polyester Control Tire
12-1-48	Armstrong	G78-15	Bias	4-Ply Polyester Control Tire
1-1-48	Cooper	G78-15	Bias (Low-Mileage)	Rapid, 4-Ply Polyester

* Replicate tests were performed on this tire.

the following schedule of slip angles and torques was determined as optimum and was therefore employed for all subsequent tests:

Slip Angles:

- Gaussian Random Variations; 0.3° rms
- Period of Randomness; 20 minutes

Longitudinal Slip (Torques):

- Sinusoidally Varying Torque; ± 50 ft-lb peak
- Period of Sine Wave; 10 seconds

Tire operation on the Safety-Walk surfaced steel belt of the TIRF machine generally does not always produce a tread texture similar to that found on vehicle-worn tires. In contrast with the tactilely smooth surface of road-worn tires, following TIRF tests, rubber particles are found adhering to the tread surfaces which produce a tactile sense of coarseness and tackiness. To alleviate this problem, cornstarch (mean particle size of about 10 microns) was blown into the tire-roadway interface at a rate of about 23 lbs for a 1000-mile test or approximately 13 hours of operation. The use of cornstarch resulted in the smooth tread surface texture that was one of the program objectives.

In the early stages of the checkout tests, close visual scrutiny was maintained over the belt surface for possible buildup of rubber contamination. After one test of 200 miles, a sample of the Safety Walk was examined with a scanning electron microscope (SEM). No evidence of belt contamination or deterioration was found. This finding corroborated our previous experience (2) with tread wear testing.

The second phase of the test effort was devoted to the accumulation of wear data on six different tires subjected to the fixed-upon wear schedule of slip angle and torque. Table V identifies the tires. Prior to test, each tire was subjected to a 15-minute, 20-mile break-in. This break-in was necessary to permit the tire to become adjusted to the wear cycle. Prior tire operation had conditioned the tire and consequently a different tire set takes place when it is first subjected to the wear cycle. Such tire "memory" effects can result in an erroneous apparent wear, or even growth, if not compensated for by preconditioning. Pre-wear measurements were made subsequent to this break-in run but after a minimum four-hour tire soak in a temperature-controlled environment. All tread wear tests were 1000 miles in length and continuous in extent except as otherwise noted. Tread surface temperatures, as sensed with an infrared radiometer, varied between 98°F to 116°F for the tires shown in Table V which was well within the specified tolerance limit of 200°F.

TEST RESULTS

A summary of the numerical tread wear rates measured for the six test tires is shown in Table VI. The tread loss in mils per 1000 miles (kmi) was measured at a normal load of 1170 lbs (85% of T & RA rated load) at an inflation pressure of 24 psi. An examination of these data does indeed show that wear rate for the acknowledged low-mileage tire was indeed significantly larger than that for the high-mileage tires.

A chronology of the test events is important and instructive in an understanding of the results shown in Table VI. Firstly, the testing sequence occurred in accord with the serial listing in Table VI.

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As verified by SEM photographs, the first specimen (tire #7-1-48) was tested on a substantially clean belt surface despite the fact that several hundred miles of checkout tests and the entire wear program of Reference 2 had been conducted on the same path of this first test, a road surface sample was removed for SBM examination. Since there had been no history of belt contamination by rubber during any previous wear tests, the test schedule was continued despite the unavailability of the SBM for immediate sample analysis. Visual inspection of the roadway surfaces was continued and no perceptible differences could be visually or tactilely discerned between the tire track area and other areas of the belt.

The remaining two high-mileage radials (#8-1-48 and #9-1-48) were tested in succession. Wear rate data for the three radials showed a decreasing trend; 9.23; 8.16 and 7.58 mils/kmi, respectively. Testing then continued on the two control tires (#11-1-48 and #12-1-48) with the 1000-mile test on the former being completed on a late work shift preceding a weekend. On the next work turn, testing began on tire #12-1-48. Upon reducing the data for tire #11-1-48, an apparently unrealistically low wear rate of 5.31 mils/kmi was obtained suggesting a change of roadway surface characteristics. Testing on

tire #12-1-48 was immediately stopped. At this point in time 360 miles had already been accumulated.

A sample of the roadway surface in the tire track was removed and examined with the SEM. Severe loading with rubber was evident in this sample which had accumulated 4360 miles of testing since the initial SEM photograph. Figure 6 shows SEM photographs of the contaminated patch at two levels of magnification. Figure 7 shows similar loading apparently occurred during the time that the bias tires were being operated on the roadway.

Removal of rubber from the belt was accomplished by using a "scrubbing" tire. This operation involves mounting an available spare tire on the machine and subjecting it to a nominal normal load. With a roadway speed of 40 mph, the tire is manually steered to discrete angles of ±5°. In approximately ten minutes of operation, the accumulated rubber was substantially removed.

Upon resumption of testing, the TIRF machine was stopped after each two-hour period of operation to check for rubber contamination of the belt. If necessary, the test tire would be removed and replaced with the "scrubbing" tire and the cleaning operation performed.

Table VI - Summary of Tread Wear on Six Tires

Tire Identification	Shore Hardness	Wear Test Run	Average Wear mils/1000 mi.
Dunlop Hi-Mileage Radial #7-1-48	AVG = 61.3 s = 1.1	1000 mi.(1st)	9.23
Dunlop Hi-Mileage Radial #8-1-48	AVG = 62.3 s = 0.5	1000 mi.	8.16
Dunlop Hi-Mileage Radial #9-1-48	AVG = 61.3 s = 0.7	1000 mi.	7.58
Armstrong Control Bias #11-1-48	AVG = 55.3 s = 0.7	1000 mi.	5.31
Armstrong Control Bias #12-1-48	AVG = 57.7 s = 0.5	1000 mi.*	8.22**
Cooper Lo-Mileage Bias #1-1-48	AVG = 59.2 s = 1.3	1000 mi.	16.91
Dunlop Hi-Mileage Radial #7-1-48	AVG = 61.3 s = 1.1	1000 mi.(2nd)	8.57
Dunlop Hi-Mileage Radial #7-1-48	AVG = 61.3 s = 1.1	1000 mi.(3rd)	6.95

*First 360 mi on rubber-contaminated belt, final 640 mi on cleaned belt.
**A value of 9.86 is obtained by numerically correcting for first 360 mi (See Text)

VIEW ANGLE = 45°
MAG. = 15X
ROADWAY DIRECTION OF TRAVEL ⟶

VIEW ANGLE = 45°
MAG. = 100X
ROADWAY DIRECTION OF TRAVEL ⟶

PATCH HISTORY: 4360 MILES RUNNING, TIRES #7, 8, 9, 11 AND PART OF #12

FIGURE 6   SEM ANALYSIS, CONTAMINATED ROADWAY SURFACE

VIEW ANGLE = 45°
MAG. = 13.2X

VIEW ANGLE = 45°
MAG. = 100X

PATCH HISTORY: BRAND NEW PATCH

FIGURE 7   SEM ANALYSIS, NEW ROADWAY SURFACE

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The final 640 miles on tire #12-1-48 were accumulated on a clean belt surface. A composite wear rate of 8.22 mils/kmi (Table VI) was determined for this tire which had been operated on "loaded" and clean roadway surfaces. If it is assumed that the wear rate appropriate to the initial 360 miles is that determined for tire #11-1-48, then a wear rate of 9.86 mils/kmi can be attributed to the last 640 mils of wear tests performed on the clean roadway.

A wear rate of 16.91 mils/kmi was obtained from tests on the low-mileage bias tire. An examination of the meridional wear measurements indicated that this tire exhibited a higher asymmetry of cross-tread wear than any of the other tires. The front outer rib* wear was significantly larger than that of the other three ribs measured. This tire is believed to have experienced highly asymmetrical lateral forces which resulted in the non-uniform wear. Most of the tires tested exhibit some asymmetry of wear but of a much smaller degree. Average wear rates for the two frontal ribs were generally larger than those for the two rear ribs.

Two replicate test runs on a high-mileage radial tire (#7-1-48), which had been tested previously, concluded the program. This tire had been tested initially on a clean roadway surface for a continuous 1000 miles. Thus to

make the data comparable, the replicate tests each were begun on a cleaned roadway and permitted to continue, uninterrupted for 1000 miles. A summary of the wear rate data collected on the respectively-tested high-mileage radial tire is given in Table VII below.

These wear data show a consistent decrease in wear rate with accumulated mileage. A reason for this trend cannot be reliably established based on the available information. It may be conjectured that this trend is an inherent characteristic of this tire. Another possibility may be progressive wear of the belt roadway surface with prolonged usage. Some SEM photographs which were taken near the completion of this program showed evidence of breakup of the individual asperities in the belt surface. Figure 8, a photograph of a sample which had experienced considerable usage, graphically illustrates a grit particle that has fractured and apparently lost a portion of its original bulk.

Table VII - Results of Replicate Wear Tests on Tire #7-1-48

Wear History	Wear Rate, mils/kmi
1st 1000 miles on TIRF	9.23
2nd 1000 miles on TIRF	8.57
3rd 1000 miles on TIRF	6.95
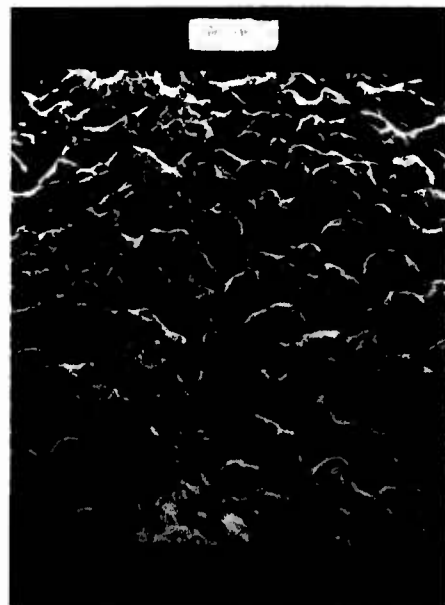
VIEW ANGLE = 45°
MAG. = 15X
ROADWAY DIRECTION OF TRAVEL ⟶

VIEW ANGLE = 45°
MAG. = 100X
ROADWAY DIRECTION OF TRAVEL ⟶

ROADWAY HISTORY: TESTS ON ALL SIX TIRES PLUS 2ND 1000 MILES ON
TIRE #7-1-48, AFTER CLEANING

PATCH H
FIGURE 8   SEM ANALYSIS

*Viewing the tire as if it were mounted in the right front position of a vehicle.

Belt wear is a subject that requires further investigative study.

In summarizing the test results, the important conclusion is that TIRF-determined wear rate data do permit a gross rank ordering of the test tires according to the RMA selection of high, control and low-mileage radial tire shows the least wear, the bias (control) tire shows an intermediate level of wear and the low-mileage bias tire shows the largest wear rate by a factor of two relative to the radial tire.

Table VIII - Rank Order of Tires as Regards Wear Rate

Tire Description	Wear Rate, mils/kmi
High-mileage radial-Dunlop	8.25*
Control (bias) - Armstrong	9.86**
Low-mileage bias - Cooper	16.91

*Average of three tests on tire #7-1-48
**Calculated value

CONCLUSIONS

Based on the test results and the operational experience gained in executing this experimental study of a laboratory evaluation of tire tread wear rates, involving accumulated mileages of 5000 miles on high-mileage radial tires, 1000 miles on low-mileage bias tires and 2000 miles on control (bias) tires, the following conclusions are warranted:

- Gross rank ordering of tires as regards resistance to wear was demonstrated.
- A tire test technique for TIRF was developed that is capable of producing specified wear rates and tread surface textures resembling those of road-worn tires.
- Electromechanical tread-depth measuring instrumentation was demonstrated to be satisfactory in determining normal severity wear rates.
- Replicate tests showed consistently decreasing wear rates.
- Assymetrical cross-tread wear was experienced with the wear rate for the front half of the tire tread generally exceeding that of the rear half.
- Wear tests on the order of 1000 miles in length show potential in producing meaningful data on the TIRF machine.
- Rubber contamination of the roadway was experienced with the most rapid buildup occurring with bias ply tires.
- Mechanical means can be efficiently used to clean rubber-contaminated belt surfaces.

RECOMMENDATIONS

1. Related to future test operations:

    - Wear tests employing consistent lateral force variations rather than slip angle variations should be considered to attain more uniform wear across the tire tread surface.

    - Wear tests should impose consistent tractive force variations rather than wheel torque to achieve a uniform distribution in longitudinal tread wear.

2. Related to future studies directed to improvement of the laboratory technique:

    - Development of methods for detection and control/removal of rubber contamination during test operations.

    - Evaluation of Safety-Walk durability in terms of constancy of surface texture characteristics.

    - Identification and control of test conditions leading to variability in wear data.

    - Development and implementation of an improved wear-measuring device that provides significant improvement in the quality of the data and efficiency in measurement relative to the electromechanical device described herein.

    - Correlation of TIRF wear data with those obtained from controlled road tests and other test facilities.

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QUESTIONS AND ANSWERS

Q: Have you taken tires of the same manufacturers from the same batch and run repeated tests on them?

A: We did not do so on this particular program. We have another study underway on different kinds of tires. These are military vehicle type of tires but we don't have that much data from that effort that will help here.

Q: What maximum load range do we have over there?

A: Passenger car balance capability is 4,000 pounds.

Q: You indicated that the wear rate keeps dropping off, that it never reached a constant level. Does it eventually level off?

A: We don't know. There wasn't time to conduct any further tests to see whether the wear rate did in fact level off. I'm not quite sure but I think that the RMA had some road test data, which we were not privy to, that indicated that there was some decrease in wear rate with mileage for the road tests. It has been said about tires many times that as tires wear, their wear rates change. Generally wear rate decreases with wear. This is more pronounced for radial tires than for bias-ply tires. Again, we have not conducted such a test in this particular program and, to do it right, you have to continue this kind of test. The tire was run for 1,000 miles at a time and the wear was measured. Some three months later for another 1,000 miles. We'd like to continue that throughout the entire life of the tire and make those continuous measures.

Q: Did you check this tire for nonuniformities before testing and did you find any kind of relationships between the tire uniformity and wearing?

A: No, we did not make any checks in terms of any run-out, physical or geometrical distortions in a tire to begin with. One of the objectives of this program was to determine a method for short duration wear. We would take a new tire, which would have a minimum amount of break-in and running, and run it for a very short distance so that the wear would be very small. If you have nonuniformity in the tire it's reasonable to assume that it would wear nonuniformly, but if you think about the amount of variation you'd have around the tire in terms of its wear, when you're only wearing off five mils or so, the uniformity effect would be rather small. You'd only see it as you developed gross amounts of wear.

Q: What was the time lapse between each particular cycle of thousand miles and what was the temperature variation on the tires?

A: Well each tire generally was only tested once. Only the one tire was repetitively tested. Between the first and second test several weeks must have elapsed. Between the second and third thousand miles I'm not quite sure but the time interval was much shorter. There was a temperature limit given to us that the tire tread surface temperature should not exceed 200°F. We found on all these tests the tire temperature ranged between about 96° and 120°F. The tires ran rather cool for this test. These are surface temperature measurements not internal measurements. In terms of the time between measurements they varied. The shortest time we would permit would be four hours, because it was required to expose the tire to a four hour soak before all the creep and thermal stresses were stabilized and meaningful tread depth measurements made. Beyond that point, the time was not a great factor; it was a very small factor.

RELATIONSHIP BETWEEN FLAWS AND FAILURE
IN PNEUMATIC TIRES AS IDENTIFIED BY ULTRASOUND AND ROAD TESTS

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A test was conducted to determine whether flaw character-istics found by reflection ultrasound correlate with tire performance during destructive testing. This work was done in conjunction with actual road tests to determine whether there is a correlation between tires destructively tested by roadwheel and those tested on the highway.

The test consisted of selecting a number of retread tires of known characteristics and pairing them in a way that will randomize any characteristics which might tend to con-found the data. The tires were then inspected using the three nondestructive testing techniques known to have the most promise: (a) reflection ultrasound, (b) x-ray, (c) trans-mission ultrasound. After the inspection, the tires were then run on a roadwheel on a modified endurance test. Any failures were noted and compared with the results of the inspection.

A population of 109 tires was obtained for evaluation on both roadwheel test and road test. The split was 75 tires to road test and 34 tires to roadwheel test. In order to assume a random selection for both road and wheel test, the tires were broken down according to major construction cate-gories: bias, fabric belted, glass belted, radial cold cap, and radial hot cap. Tires for the wheel test were selected pro-portionally from each of these groups with approximately one-third of each major category going to wheel test and the balance to road test.

Of the 34 tires in the wheel test, ultrasound identified ten as having significant damage either before or after retread-ing, of which six failed during the wheel test. The other four tires showing damage were analyzed and showed damage of sufficient variety to warrant consideration as a failure.

AUTOMATIC ANALYSIS OF HOLOGRAPHIC INTERFEROGRAMS

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INTRODUCTION:

Holographic Non-Destructive Testing (HNDT) has proved to be a useful technique for testing tires. Internal ply separations, voids, low adhesion levels, non-uniformity, multiple cord fractures, carcass to belt damage, foreign object contamination, and mold pinch are some of the tire defects that have been identified using HNDT. The usefulness of such data has led to an increased use of and dependence on HNDT for critical testing applications. Indeed, some airlines now require all of their retreaded tires to be inspected using HNDT.

This increased dependence on HNDT has created problems related to the gathering, analyzing, recording, and storing of the data. It has been clear to users for some time that if HNDT is to be a viable tool that can be used in a production environment, then some type of computer assistance will be required in gathering and analyzing the data.

This paper describes the progress that has been made at Industrial Holographics, Inc. to provide computer assistance to gathering, recording, and analyzing HNDT data.

FIGURE 1
I.H.I. COMPUTER CONTROLLED TV VIEWING STATION

DATA HANDLING AND RECORDING AIDS:

With several hundred tires per day being tested on some holographic tire testing machines, the handling and storing of the holograms quickly becomes a critical task. The ability to identify a particular hologram without having to view the reconstructed image can greatly ease the handling of the holograms. The newest holographic interferometers used in the IHI tire testing machines include the capability of automatically writing an identification number on the film. This identification number is automatically incremented for each new tire. Under computer control, several different holograms at varying vacuum levels can be recorded automatically for each sector of the tire. The vacuum level and sector number are automatically written on each frame of the film for easy identification.

In order to analyze the data and document the results, the hologram is inserted in a TV viewing system that displays the fringe pattern on a video monitor. A photograph of this computer controlled viewing system is shown in Fig. 1. The location of defects in the tire can be pinpointed by superimposing a grid pattern on the fringe system with the grid lines separated circumferentially by 15°, as shown in Fig. 2. The proper grid lines for different sectors can be displayed by pressing the sector number on the keyboard. The number of sectors per tire can be set to 2, 3, 4, or 6 depending upon the number of frames made during the test. This TV grid system eliminates the need to grid the individual tires. Only a single reference mark in the center of the first sector needs to be put in each tire.

The keyboard can be used to type any alphanumeric data on the screen. Full editing capability is provided—including insertions and deletions. Special symbols can be used to identify separations (*), non-uniformities ($\sim$), low adhesion regions (@), and bad splice areas (/, \). An example is shown in Fig. 3. A permanent hard copy record of this image can be made with a Polaroid camera, as shown in Fig. 4. Alternatively, one can output the alphanumeric data
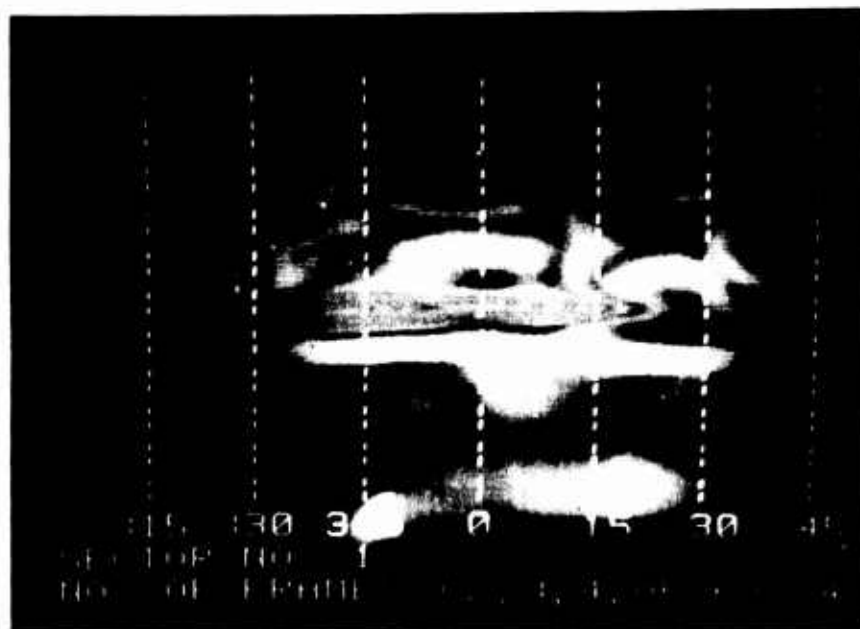
FIGURE 2
VIDEO MONITOR DISPLAY OF FRINGE PATTERN WITH SUPERIMPOSED GRID LINES
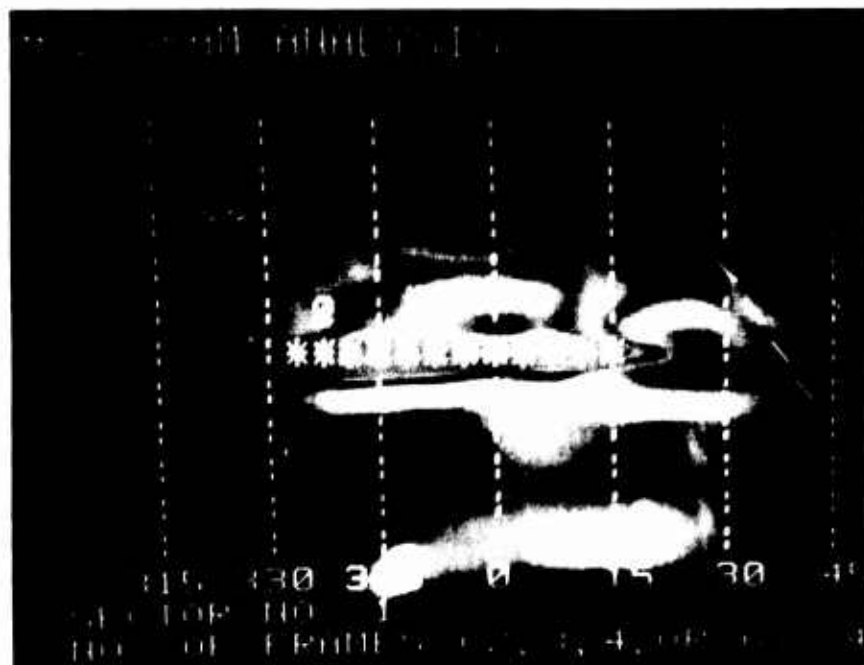
FIGURE 3
THE HOLOGRAM IMAGE CAN BE ANALYZED BY
TYPING SPECIAL DEFECT SYMBOLS ON THE VIDEO MONITOR.

FIGURE 4
RECORDING THE IMAGE ON THE VIDEO MONITOR WITH A POLAROID CAMERA.

and grid lines to a printer to give a permanent charting of the hologram, as shown in Fig. 5. The special defect characters (*, ~, ω, /, \) can be printed in red for emphasis and ease in reading the charts.

The system described above greatly simplifies the task of reading, interpreting and documenting holographic interferograms. However, this task must be carried out by a skilled person who is trained to recognize tire defects associated with fringe anomalies. It is clear that if HNDT is to be used on a widespread basis in a production line environment, then some type of computer assistance in the actual analysis of the holographic fringe pattern will be necessary.

image. The totality of possible measurement vectors defines a feature space in which the classifier operates.

A wide variety of features can be extracted in the preprocessing stage. However, there are certain desirable characteristics of features that are likely to prove useful in HNDT. These include 1) vacuum independence, 2) ease of computation, 3) spatial and size independence, 4) good class discrimination, and 5) proper scaling and normalization.

Once a feature vector has been defined, the classifier/trainer block in Fig. 6 uses the feature vector either to
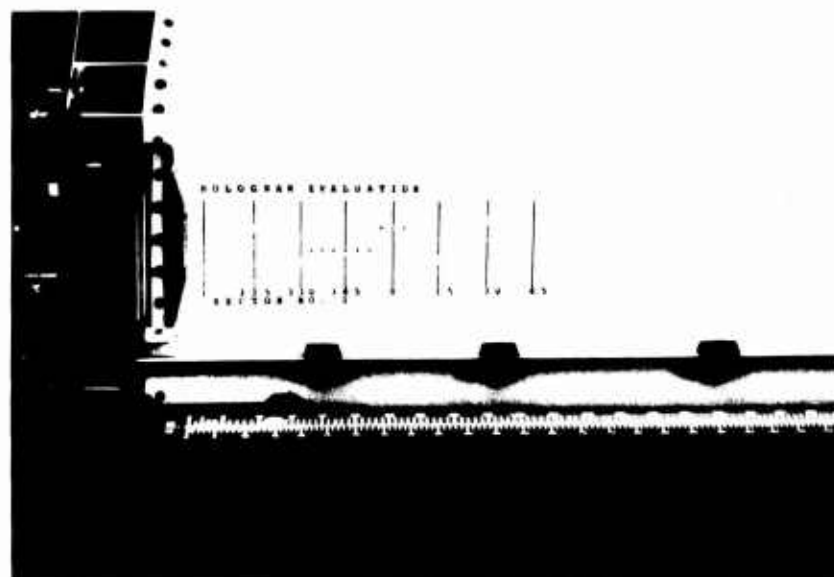
FIGURE 5
THE HOLOGRAM EVALUATION CAN BE PRINTED BY THE COMPUTER
ONTO A HARD COPY OUTPUT DEVICE.

COMPUTER ANALYSIS OF HOLOGRAPHIC FRINGE PATTERNS:

Two applications of computer analysis of holographic fringe patterns are likely to prove useful in HNDT. One application will be to simply accept or reject a tire. A second application will be to flag suspicious tires for further detailed interpretation by trained personnel.

The system shown in Fig. 1 has the capability of scanning the holographic fringe pattern and storing the digital data in the computer memory. A block diagram of a pattern recognition system that can be used to analyze the holographic data is shown in Fig. 6. The scanned video data is fed to a preprocessing block in which certain features of the fringe pattern are extracted. These features form a measurement vector x which characterizes a particular

BLOCK DIAGRAM OF A USER TRAINED PATTERN RECOGNITION SYSTEM

FIGURE 6

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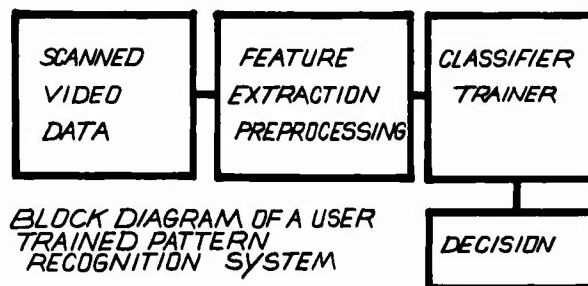
identify an unknown measurement (classify) based on previous experience, or to help add to its experience (train). The classifier, based on its experience, associates every region of its feature space with a particular class (e.g., accept, reject, unknown). A decision is then based on which region of the feature space a particular measurement vector occupies. There are a variety of training and classification algorithms that could be used in the classifier/trainer stage. However, for HNDT the desirable characteristics of a classifier include 1) nonparametric, 2) real time capabilities, 3) interactive, 4) trainable over time, 5) capable of operating with a limited sample set, and 6) ease of operation. Our experience has shown that it is possible to achieve most of these characteristics in a single classifier.

SUMMARY:

In order for HNDT to play a central role in tire testing, some type of computer aid for handling, recording and analyzing the data is necessary. This paper has described a system that is being developed at I.H.I. that takes a major step in this direction. The basis of the system is a TV viewing station that displays the holographic fringe system on a video monitor. The system can be expanded by adding a microcomputer and keyboard that allows an operator to superimpose a grid pattern and any other alphanumeric data on the screen. Hard copies can be made on Polaroid film or a printer. The complete screen data can be stored on video tape. Alternatively, the charted information about each hologram can be stored on a floppy disk for later retrieval.

The fringe data can be scanned, and from computed features the computer will either classify the hologram, or, at the option of the operator, use the measurement as training data for future classifications. Initial experience gained in using the system indicates that it is a useful aid to the human interpreter and a promising tool for relieving the human operator of actual decision making.

COMMENTS UPON THE PAST, PRESENT AND FUTURE OF
HOLOGRAPHIC NDT OF PNEUMATIC TIRES

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For those of you who are not familiar with holography, I would like to begin by introducing you to the basic principles and how we, at I.H.I., incorporate them into a double exposure holographic interferometer which is used in our tire test equipment.

Simply stated, holography is a process of three-dimensional photography. Figure 1 graphically shows the setup to record an image in a photographic media that can be displayed in three dimensions. A coherent or single frequency light is used. As shown in the figure, a laser is used for this single frequency light and it is split into two distinct paths—one path, called the object beam, is used to illuminate the object and is reflected back to the film plane; the second path, called the reference beam, is brought directly onto the film plane. It is the interference of the reflected light wave coming from the object and the light wave from the reference beam that creates an interference pattern that is recorded on the film. When the film is illuminated by a source similar to the original reference beam, the object will be reconstructed in three dimensions. Figure 2 demonstrates this reconstruction.

By using a double exposure holographic technique, an interferometer can be constructed to measure very small movements of the object when it is stressed. Figure 3 demonstrates this basic principle. If the object is holographed when it is at a steady state condition, and a second hologram is taken on the same film frame after the object is stressed to that shown by the dotted line, this small move-

ment will change the length of the reflected light path. The difference in optional path length creates a series of interference fringe lines as shown. Since the object has moved uniformly toward the film plane, the interference fringes are horizontal and uniform.

VIEWING OF THE 3-D IMAGE

FIGURE 2

RECORDING OF A HOLOGRAM

FIGURE 1

HOLOGRAPHIC INTERFEROMETRY
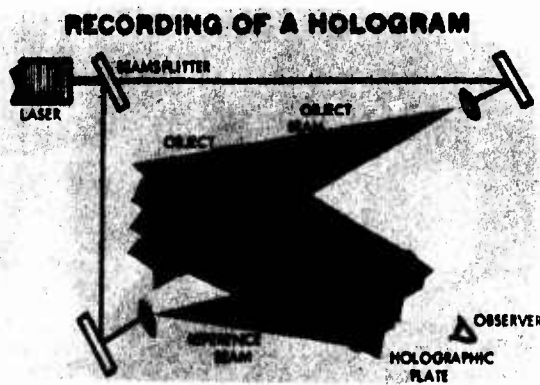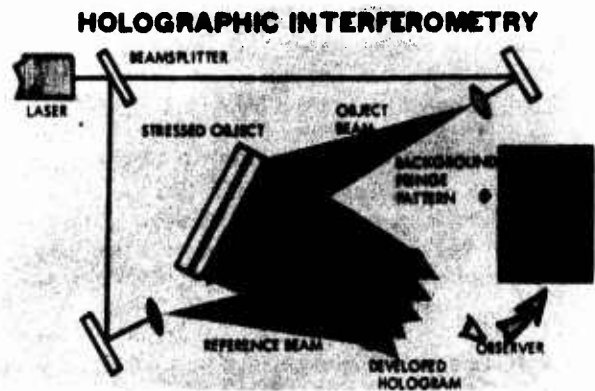
FIGURE 3

Let us consider a tire with a ply structure and a void between the plies as seen in Figure 4. We use the same procedure again and take a hologram of the tire at atmospheric pressure. We stress the tire by introducing a vacuum around it. The vacuum creates a bulge at the area of the separation. If we take a second hologram superimposed over the original hologram, the fringe lines would be distorted in the area of this bulge. In fact, a topographical map of the bulge would be created in this localized area while the background fringes in the areas of uniform stress would still be horizontal and uniform. Any condition within the structure of a tire that creates a non-uniform stress such as fatigue, separations, non-uniformity in the construction, low adhesion, overlapping of splices, and uneven cord tensioning will have a distinct holographic fringe pattern. It is these basic principles and the procedures that are used in our holographic tire test equipment.

Figure 5 shows the original holographic tire test equipment built by G.C.O. I will start with this original equipment and discuss how this basic design has been expanded and improved over the years. Originally, the laser was mounted in back of the test platform which was rather inefficiently isolated from vibrations. Through a series of mirrors, the laser light was brought around from the back and into the camera which is located at the center of a rotating table. The tire was placed over the camera and rotated around it. These old units used a helium-neon laser which was low in power and had a considerable light loss within the system. As a result, long shutter opening times (3 to 5 seconds) were necessary which made the total system sensitive to vibration and outside interference. The coherence length of the light was short, therefore limiting the size of the tire that could be inspected. The electronic controls of this unit were old style vacuum tubes and magnetic relays. High voltage contacts and the like made the entire electrical system less than trouble-free. In spite of all these adverse characteristics, there are still a number of these machines performing daily tire inspection at locations around the world. Some are still in their original condition and some have been modernized and updated.

The K60 unit shown here in Figure 6 was the first attempt. The test platform is changed to mount the laser pointing directly into the camera. The dome size was increased. A Krypton-ion laser was introduced to give a higher power, longer coherence length, single frequency light, thus reducing shutter opening times. A new pneumatic mount system was introduced to reduce vibration effects.

A third generation machine, the Industrial Holographics Model K160, shown in Figure 7, was the first holographic test unit to be placed in on-line production situations. This unit has been, and still is, the primary unit being used to inspect retreaded high speed aircraft tires. While this unit is somewhat similar in appearance, there are some significant differences to be noted. The system uses special heavy

HOLOGRAPHIC INTERFEROMETRY

FIGURE 4

FIGURE 5
G.C.O. MACHINE
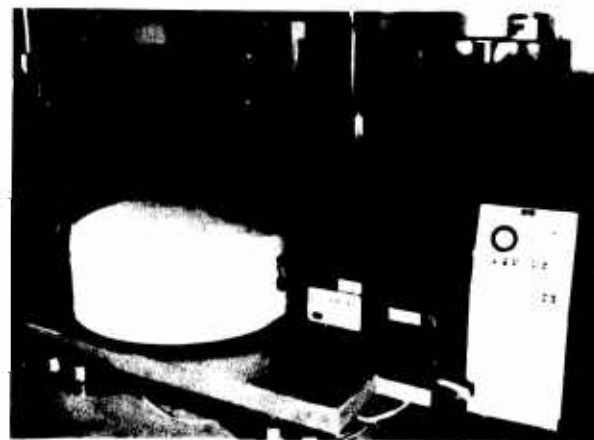
FIGURE 6
I.H.I. MODEL K60
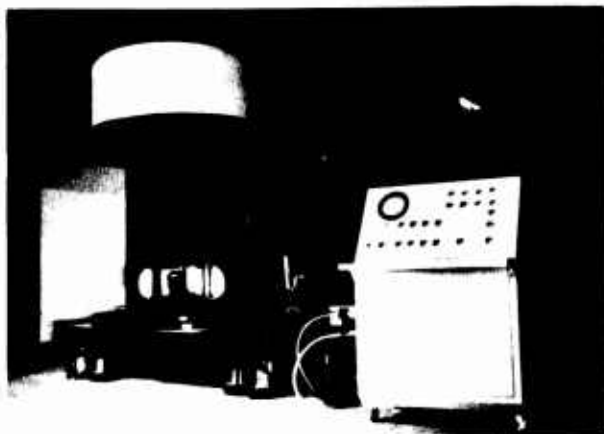
FIGURE 7
I.H.I. MODEL K160

industrial environments. As before, a Krypton-ion laser is positioned so that the incoming light enters directly into the camera optics. A new laser cradle mount system is employed for ease of alignment. The Krypton-ion laser uses an oven heated etalon for a high power, stable single frequency light with long coherence lengths. Shutter speeds are reduced to less than one-tenth of a second. The dome lift mechanism has been changed to a high speed pneumatic unit. The turntable drive unit is changed to a gear drive system which allows for fast, precise positioning of the tire during rotation. Another major advance in this generation machine was the introduction of a conventional, commercial, solid state controller using Allen-Bradley logic cards for sequence control. Figure 8 shows the back of the controller with the rack of control logic cards, which are throwaway type boards available from any Allen-Bradley supplier. In addition, precise timing delays have been introduced through the use of thumb wheel timers shown here on the left.

The overall enhancements and goals in the design of this machine were to achieve a reliable unit which could be operated as an on-line inspection device in moderate volume production facilities, and also as a research and development tool or Q.C. sampling tool. These goals have been achieved and this unit is still used as a standard holographic tire test unit being sold around the world.

This same basic machine has been scaled up to our Model K172/194, see Figure 9, which is a dual purpose machine that is the same as the K160—only with a 72 inch dome. The second configuration is for testing small earthmover tires up to 92 inches in diameter.
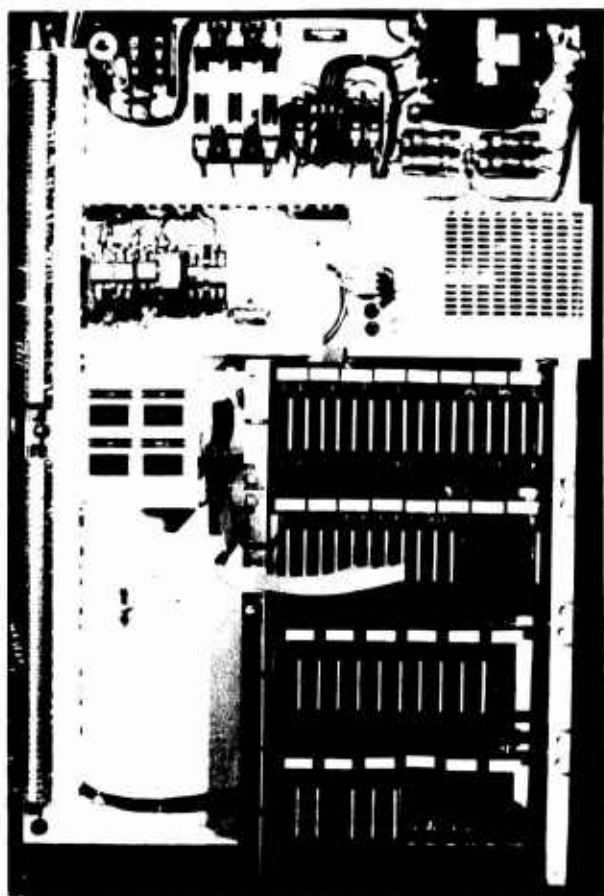
FIGURE 8
ALLEN-BRADLEY SOLID STATE CONTROL PANEL

FIGURE 9
I.H.I. MODEL K172/194

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A fourth generation of machines is currently in production. Using some of the basic concepts of the K160, a new high speed production unit, designated our Model K248, (see Figure 10), has been designed and produced to meet high volume requirements. Along with available automatic film

FIGURE 10
I.H.I. MODEL K248

processing, this unit is designed to test more than one thousand (1,000) tires per 24 hour period. As can be seen, this unit is a dual-domed unit with two test positions. The unit is redundant from a systems standpoint in that it has two on-board lasers, two vacuum cabinets, and each dome is capable of being cycled independent of the other. This redundancy was purposely introduced into the design to insure overall reliability and continued operation in a high production environment. While some of the basic principles of the K160 have remained, a major change in this unit has been the introduction of a microcomputer controller which has built-in automatic sequences and reduces operator skills to a minimum. The operating functions of the machine are displayed on a video monitor, as shown in Figure 11. The operator can key in machine settings such as film exposure, vacuum level, number of photographs in the film canisters and identification serial numbers, by using the keyboard below the screen. During machine operation, the lower portion of the screen flashes machine sequence messages and instructions to the operator. This information can also be used for diagnostic information that can be useful in trouble-shooting the machine.

This microcomputer incorporates new features which are not available on the standard K160. One of these features is the capability of writing information onto the firm. For instance, digital information can be entered at the start of

a new roll of film which can act as a permanent identification. During the production run, identification numbers can be entered for each tire with this identification only having to be entered for the first tire. The machine automatically increments the identification code by one (1) every time a tire is run. When the film is developed, each tire's set of holograms has its own identification number.

Another unique feature of this machine is the capability of automatically adjusting the beam ratio. This feature allows running "black" tires without painting or talcing. The beam ratio is automatically set for each tire that is placed in the machine regardless of color.

Another feature is the capability of running a calibration run totally automatic. The operator keys in a shutter setting range and a beam ratio range on the microcomputer. The machine will then automatically cycle through the vari-

FIGURE 11
I.H.I. MICROCOMPUTER
CONTROL CONSOLE

ous shutter settings and beam ratios. The shutter and beam ratio information is printed on the film, see Figure 12. After developing, the operator merely selects the optimum setting selected from the calibration run. He uses this optimum setting as an input to his exposure setting at the top of the screen. Once this setting is introduced into the computer, the computer will use this shutter setting and automatically adjust the beam ratio to obtain the selected beam ratio. This capability of adjusting beam ratio for each individual tire ensures that the optimum value is used and is totally independent of the inside tire color.

Another desirable feature that has been incorporated into the computer is an automatic series of vacuum level changes for each sector being tested. The operator can enter a lower and upper vacuum level and an increment. The computer will start at the lower vacuum level and will increment up by the specified increment until it reaches the upper vacuum level. This sequence will be shot for each sector, as shown in Figure 13. (NOTE: The vacuum is printed as the

first two digits of the identification number.) A full series of vacuum levels will be run on all sectors depending upon the number of sectors that are selected. This feature can be extremely desirable for tire development and research purposes and heavy duty tires.

A fifth generation design is being incorporated into a machine for the inspection of O.T.R. tires. These are the huge, expensive tires used on today's earthmoving equipment. We are currently in production of a machine capable of testing a tire up to 130 inches in diameter with a maximum weight of 6000 pounds. This unit incorporates the Model K248's latest technology of using the microcomputer control unit. It has two cameras which will have horizontal and vertical movement. These cameras are capable of being positioned with different views of the tire to simultaneously collect information anywhere within the bead-to-bead region of the tire. This machine will be installed as an on-line inspection tool in a major new tire manufacturer's earthmover tire plant.
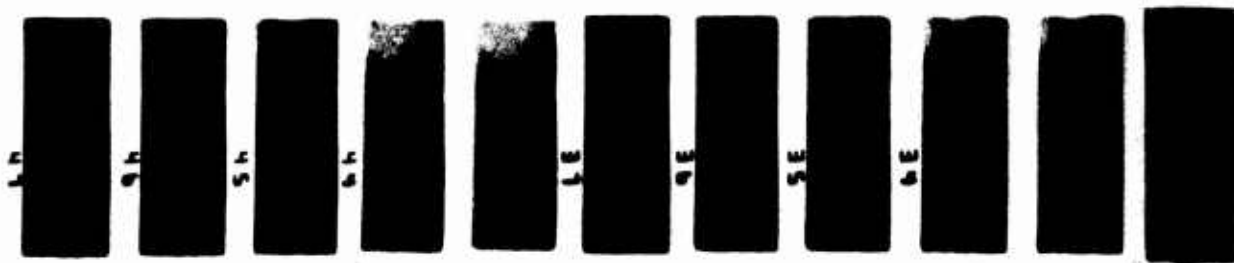
FIGURE 12
CALIBRATION RUN

FIGURE 13
MULTIPLE VACUUM RUN

One other area of primary interest has been the development of an automatic computer scan of holographic data generated by our tire analyzers. We currently have hardware available which will be the subject matter of Dr. Haskell's talk. Along with the computer analysis of the holographic data, our long-term corporate objectives have been to design and develop a machine with a reliable, reusable, real time imaging system with an on-board computer for analysis of the image. The operator will not be required to analyze the data. All decisions for "accept or reject" will be made by the on-board computer.

Our current corporate research and development programs are aimed in the direction of developing machines with these capabilities, and our ultimate objective is inspecting a passenger tire for the cost of a quarter. We believe that we are well on the way to achieve these goals, thereby making holographic tire inspection a viable, on-line production tool for inspecting every passenger tire coming off the production line.

FAILURE ANALYSIS OF AIRCRAFT TIRES
AS OBSERVED BY HOLOGRAPHY

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ABSTRACT

A review will be given of recent methods employed in the holographic non-destructive testing of aircraft tires. Comments will be made on both equipment and procedures. The prime purpose of this paper will be to answer the basic question: Do separations propagate? Dozens of specific examples of the propagation of separation in aircraft tires are presented. Test results are presented on over two thousand tires. Consequently, based on our observations, separations always propagate; many at a very fast rate. Detailed documentation of individual cases of separation propagation is provided.

This paper summarizes a study carried out on the subject of failure analysis of aircraft tires as observed by holography.

Much of the work we have been doing on aircraft tires is extremely preliminary. We have treated only a few thousand to date. Normally our testing facility tests about 20 to 40 tires per day. We have learned from truck tire testing in past years, that it takes a very large data base over an extended period of time before one can establish with any degree of credibility exactly what is taking place in terms of specific failure mechanisms. Our basic objective is an understanding of the life expectancy or durability of a tire. How does one get his money's worth out of a tire? How, basically, does it fail, and when is it going to fail? In the case of truck tires, we look at the diameter of a given separation in a tire as a function of the mileage. We follow a given tire up to 160,000 miles. For example, a quarter inch wide separation in a new radial truck tire will grow linearly as a function of mileage up to typically one or more inches within 100,000 miles. We plot the separation diameter as a function of mileage through repeated tests at various mileage points. We then observe the size of the separation just prior to the failure point. We note, within the limits of statistical error, that in general there is a linear relationship between separation size and mileage, which almost always results in separation propagation which is quite predictable in other tires of identical construction under similar road and load conditions.

Now, let us return to our discussion of aircraft tires. Aircraft studies are much more difficult. The initial sample of a given size of new R-0 tires typically have few separations in them, 1% or 2% on the average, 3% or 4% at the most.

However, after watching them beyond R-1, the first recap level, or R-2, the second recap, we will sometimes see separations suddenly appear along with a progression of poor structural uniformity in the tire. Separation will propagate at a fairly slow rate for a period of time, and then suddenly propagate almost exponentially into a quick and sudden failure. Instead of having the linear separation propagation relationship which we observe in the case of a typical truck tire with good uniform strength, we will have a situation where we may see relatively slow propagation of separation over an extended period of time which then abruptly leads into sudden separation growth as the number of landings proceed. In a typical aircraft tire, we will see a small separation sit idly by, propagating very slowly as the number of landings progress, then all of a sudden it will propagate to failure over a relatively short number of landings. Aircraft tires are complex because the propagation mechanism is critically influenced by the overall structural strength and structural uniformity of the carcass. That is, a small separation in a weak carcass may propagate very fast, but a moderately sized separation in a very strong carcass will propagate very slowly and go through a surprising number of R levels before it will lead to a terminal failure.

The result in aircraft tires is that the stretch or the elongation as a function of applied load which gives us the most significant data, as opposed to the classical mechanics case for homogeneous metals where strain data which is measured as a function of applied stress, provides us with the best information. Life is basically simple in a homogeneous metallurgical situation, a one dimensional problem where you can pull on the material with a given applied stress in pounds per square inch and measure out the corresponding strain in inches per inch. Holography testing does not provide us with strain data directly, but rather gives us the overall stretch or elongation characteristics of the carcass for a given applied load. This type of data turns out to be exactly what we need, since it reveals the general strength characteristics of the tire.

Briefly, we might note that holography is a laser photographic process which can photographically record a three dimensional view of the tire. Employing as a test method the combination of holography and interferometry, minute displacements can be measured in three dimensional objects. In the case of a tire system, it is absolutely essential to look at the complete three dimensional object, rather

than gathering data at a single point which is the typical case for metals. In a tire, the comparison between relative rather than absolute data points is crucial to the strength of materials analysis. The measurement of minute displacements in tires as a result of an applied load can lead to judgments about the quality of the tire.

Let us look at the following simple analogy which will help us to understand the manner in which we obtain the final data. Suppose we had a thinly stretched rubber membrane of which we had taken a three dimensional hologram. (A hologram is a special type of photograph taken with a laser beam.) We could then set up a very simple interferometer and look at that membrane and push it very gently forward. The image we would see as we push that membrane out would consist of rings or concentric circles which would be contours of constant displacement. As we push the membrane out, we could then generate a contour map (the contour lines on the map would represent levels of constant displacement or levels of constant height above a reference) which would tell us the general displacement from the original position. Now in terms of a tire, we want to see the overall displacement between the unstressed and stressed tire carcass. In reality, what we are trying to do is just set

Plan views of bulges caused by inner ply separation where contour lines represent constant height above a reference.

Cross sectional view – Physical change in height
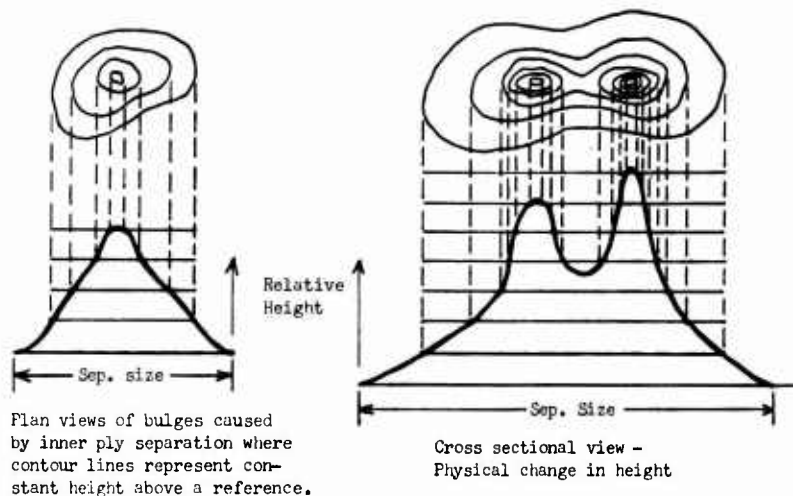
FIGURE 1A
Interferometric Contour Maps
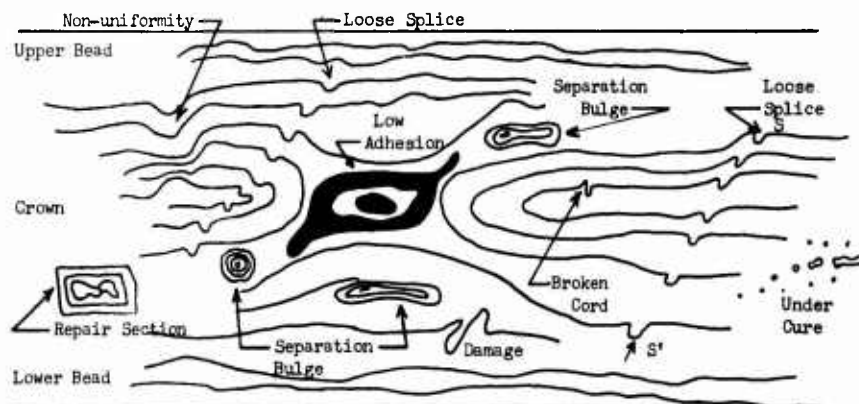
FIGURE 1B
Topographical Map of Typical Low Quality Aircraft Tire After Numerous Retreads

up a three dimensional stress-strain measurement where we can read the relative stretch or displacement out in the form of a simple image as a result of an applied stress. It is of crucial importance that we obtain our data over a region of the tire's surface as opposed to obtaining data at a single point in space which was the case prior to holographic interferometry. In a holographic tire testing machine, we take a photograph or a hologram of an interior region of a tire, say for example, a left to right view from 0 to 90 and a top to bottom view covering the tire from the top head to the bottom head as viewed from the center of the tire after we have applied a stress, which can be done by putting the tire in a vacuum, we come up with a contour map that represents to us the stretch that is produced in the tire as a result of the applied stress (note Figure 1).

To get the tire ready for testing, metal spreaders are put into the interior to hold the beads far enough apart to enable the camera to view the interior of the tire (note Figure 2). The tire is then ready to be placed into the holographic machine on a merry-go-round turntable assembly under a vacuum dome. The tire surrounds the interferometric

camera which takes the hologram. Ninety (90) to 120 circumferential degrees are automatically viewed at a time. The tire is holographed (or photographed) both with and without an applied vacuum to obtain the relative stretch caused by the applied stress. The tire is then rotated to the next 90 or 120 degree view, etc. Typical test time for a tire for the type of results we will be discussing is about two minutes (note Figure 3).

In most tires which we test, we obtain an upper mid-sidewall to lower mid-sidewall view. In a few cases, we insert mirror assemblies to provide bead-toe- to bead-toe views, as shown in Figure 4.

Now let us come back very briefly to the method. If you were to take an object and put it in a vacuum, that object being a multiple ply tire, the overall tire being tested would dilate, stretch, or elongate as a result of the applied vacuum. Our camera would record a background fringe pattern which would relate to us how the tire surface moves or stretches topographically (reference Figure 1).
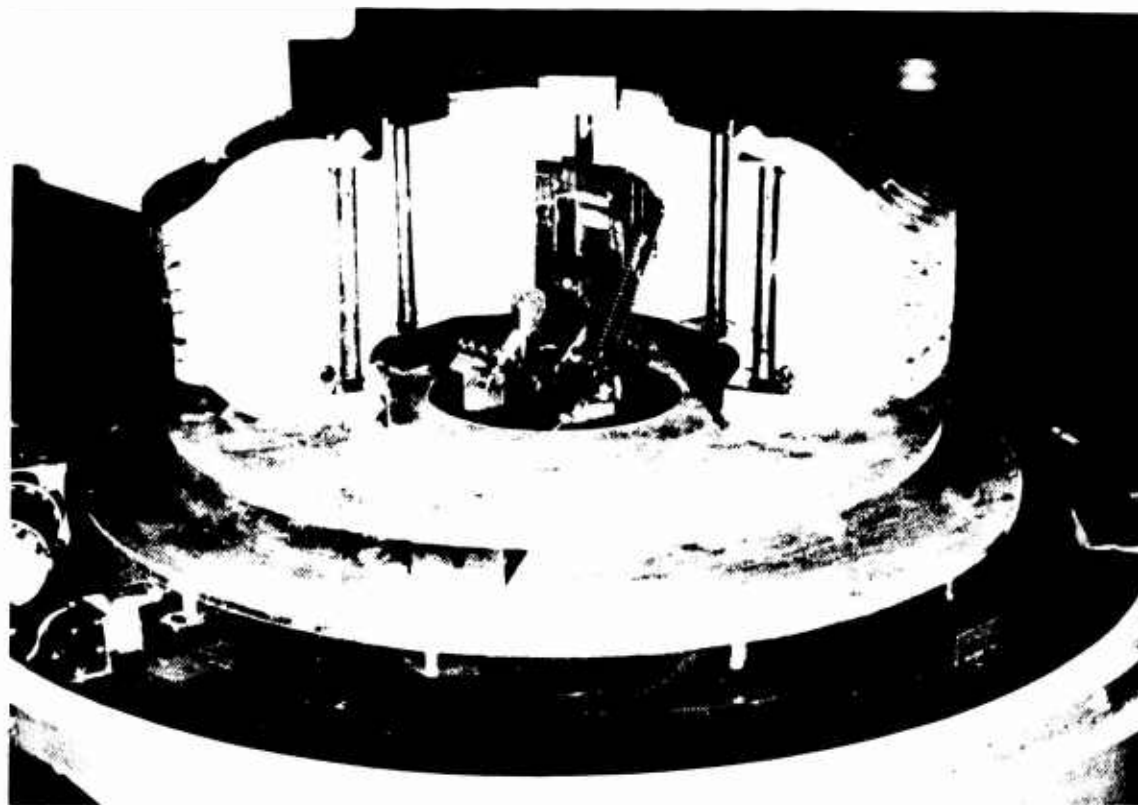
FIGURE 2
Bead Separation By Metal Spreaders

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FIGURE 3.a. Typical Test Machines For Aircraft Tire Analysis
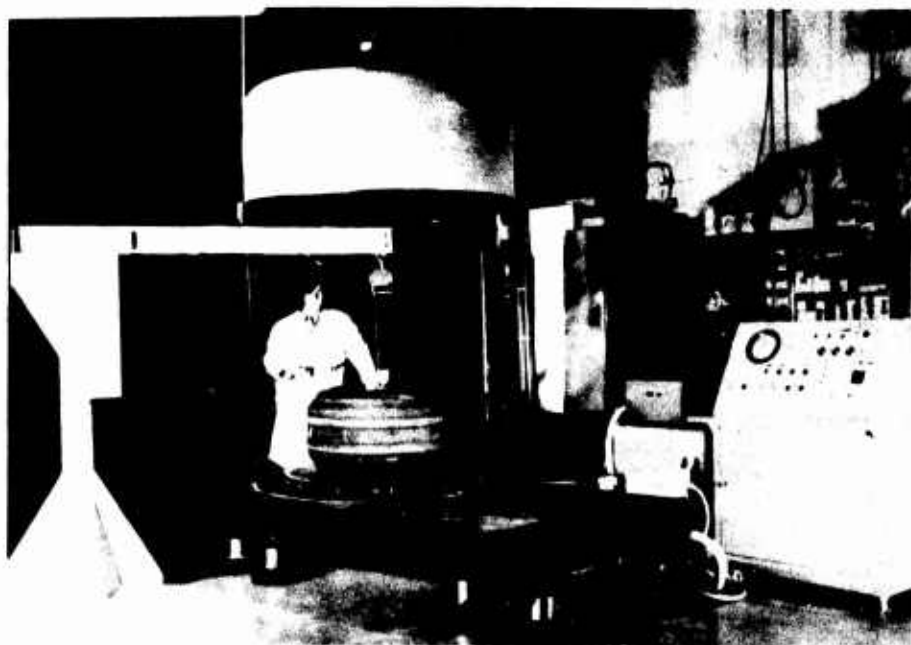
FIGURE 3.b. Typical Test Machines For Aircraft Tire Analysis

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FIGURE 3.c. Typical Test Machines For Aircraft Tire Analysis
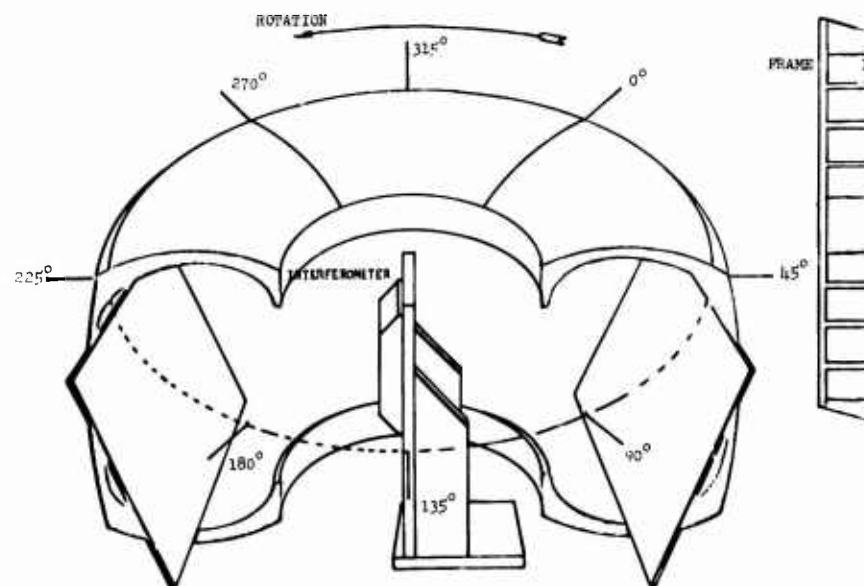
FIGURE 4.a. Bead View Holography — Mirror Placement

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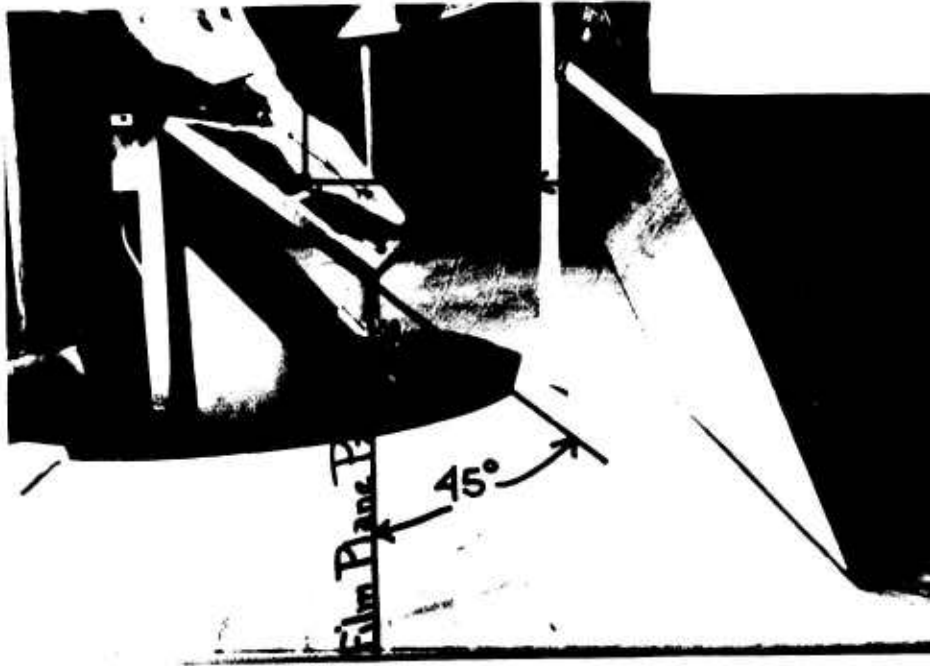
FIGURE 4.b.   Bead View Holography — Mirror Placement

FIGURE 4.c.   Bead View Holography — Mirror Placement

FIGURE 4.d. Bead View Holography — Mirror Placement

In a situation where there is an interply separation inside the structure, not only do we get this displacement as a result of having put a negative pressure on the surface, hence lifting the entire surface; but there is also an added displacement as a result of the air expansion inside the void or interply separation. Whenever we observe the concentric ring pattern of a separation, it has a background fringe structure surrounding the separation which tells us the relative strength of that region, in addition to the fundamental pattern which reveals the void or separation itself. So, in summary, we observe a background displacement pattern as well as the typical bull's eye pattern. This

pattern reveals the displacement which is associated with any separation, or lack of structural integrity as you will note in Figure 5.

Next let us explore this background pattern which reveals the general strength of the tire. For example, if we look momentarily at the turn-up region or the flipper edge of the tire and rotate the tire circumferentially (reference your observation point as being the center of the inside of the tire) and assume that the tire's internal construction geometry remains the same within very close tolerances, as does the relative strength in that region; we will then note in the hologram that the fringe lines are always uniform and very beautifully behaved as depicted in Figure 6-A. If the geometrical components inside the tire are straight and geometrically symmetric, the fringe lines or contour lines will be geometrically symmetric. The tire has stretched uniformly due to the geometrically symmetric construction detail. In other words, the fringe lines merely correspond to the stretch nature of the tire. Had there been an interply separation in the tire it would have exhibited itself with its own characteristic pattern which is a direct measure of its given size. If the separation is deep or farther away from the observer (near the tread), there will be fewer circular fringes or concentric circles. Consequently, we can resolve the general position of the separation in the structure as well as determine its relative depth in the tire. As you look from left to right, parallel to the bead, you will notice that the fringes are extremely linear and horizontal. If you take a tire in your hands and

FIGURE 5   Background — Structural Uniformity as Opposed to Structural Integrity or Separation

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6.a. Excellent   6.b. Poor
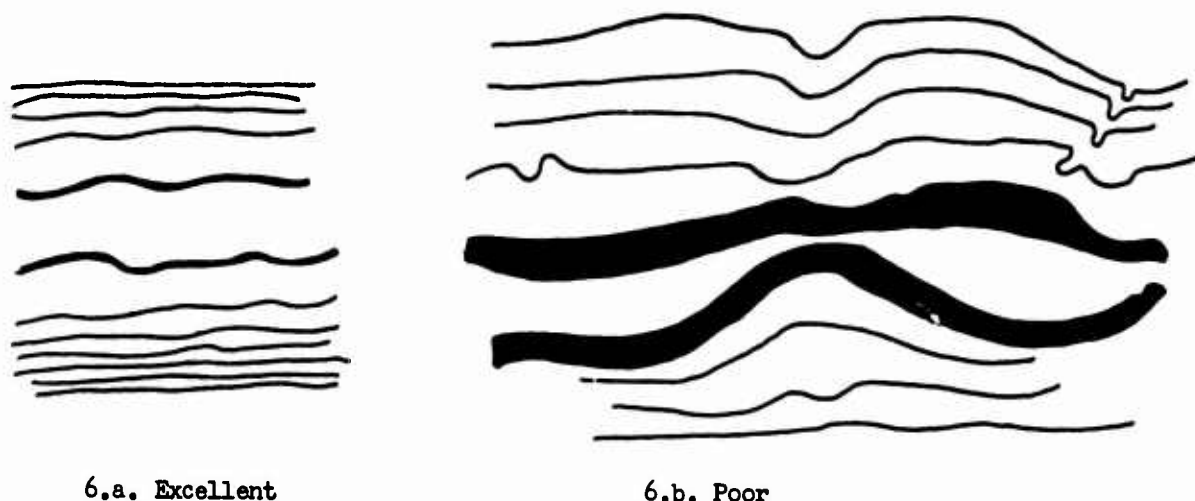
FIGURE 6 — Structural Uniformity

rotate it around your head circumferentially (with your head at the center of the tire), wherever you look circumferentially (assuming you have X-ray vision), it should be the same geometrically. On the other hand, if you observe the tire in the radial direction, there are different cross-sectional thicknesses, different strengths, and therefore the fringe spacing is different. Hence from the above comments, all holographic fringes (aside from the pattern caused from changes due to variations in the index of refraction during the measurement which enhances the read-out) run horizontially from left to right and have different spacing up and down. Now what would happen if we had a tire where there were variations in the height, say at the turn-up? This variation could lead to a variation in the strength. Then instead of the classic very uniform linear horizontal fringes, we would see fringes which wander up and down as we move circumferentially around the tire. This would mean that we are getting a different magnitude of stretch as we move circumferentially around the tire as depicted in Figure 6-B.

When a tire is constructed with near perfect geometrical proportions and such exacting geometry is further coupled with near perfect adhesion throughout, the fringe pattern will be highly uniform. This happens because the tire carcass responds, stretches, or elongates due to the applied load or stress induced by the vacuum in a highly regular or uniform manner. In other words, if the strength of the tire is uniformly symmetric, the fringe pattern will be uniform. In a highly uniform tire, we find the separation rate propagating more slowly than in the non-uniform tires. Higher shear stresses as well as higher temperatures develop in non-uniform tires resulting in the higher propagation rates. For example, a quarter inch separation in a 40 x 14 aircraft

tire will go through 200 or 300 cycles or landings before propagating significantly if it is in a very strong carcass. If, on the other hand, it is in a very weak carcass as revealed by non-uniform fringe contour lines, it may propagate to failure within 25 to 30 cycles, especially if it is in the shoulder region. If the background fringe pattern is geometrically non-uniform, cord tension will vary over a greater range and fatigue will set in much faster. Separations will evolve more readily and will propagate at a higher rate. If however, the background fringe pattern is uniform, separations will only rarely appear over the first hundred cycles; and when they do, they will propagate much more slowly. Hence in aircraft tires, it is particularly important to take this background structural uniformity into account when predicting the rate of propagation of a given separation at a given location. The performance characteristics of a given tire construction will be critically dependent upon the observed state of the tire's structural integrity.

In summary, it should be noted that a large structural uniformity data base must be established before realistic acceptance-rejection criteria can be established on a given type of tire. The existence and size of separation is not nearly as important an observation as the overall structural uniformity, unless of course the separation is well over an inch in diameter and it is in a critical geometrical position. One must always judge the criticality of the size of a given separation as a function of the observed carcass strength which is revealed by this general structural uniformity.

The type of data which we reference here, can be obtained over a period of time by routine monitoring of commercial carrier fleets. Tires which develop dangerous separation

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characteristics can be run out on indoor test wheels to minimize the danger to the commercial operation.

Now there are some basic questions at this stage which we should begin to ask ourselves. What is the incidence of interply separation in a typical sample of aircraft tires? Given the fact that they exist in a given structure, what is the probability of failure during the original tread life: R-0, or R-1; the first recap level, or R-2: the second recap level, etc. In general, there are fewer separations in aircraft tires than most of us realize. It turns out however in a few isolated cases, that abnormal outcropping of separations in given tire sizes do exist as a result of construction mistakes, poor workmanship, contamination, etc. Often modest changes in tire construction can reduce separation problems.

One of the common causes of separation in new tires is due to the existence of pieces of "poly" left in the tire when these protective sheets are pulled off the original stock material during the building of the tire. An example of dealing with separation problems by changing construction details in 40 x 14's is to reduce cord diameter and increase skim coat thicknesses to provide greater insulation between plys. In one particular test carried out on 100 new 49 x 17 aircraft tires, the author found that 3% of the tires contained separations over one inch in diameter at the turn-up edge due to pieces of poly. The fact that at least one of these could have lead to a critical failure within its normal life expectancy is without a doubt.

But now let us come back to the basic point. Given the fact that separations do exist in aircraft tires, how many exist, and when they do exist in a given construction, how fast do they propagate? When and under what circumstances do they lead to failure? What is the proper time to take tires off of a given system so as to get the maximum usefulness out of a tire purchased?

To get a preliminary feeling for the answers to these questions, (a final answer is not yet possible), six descriptions follow of random samplings from a mixture of R levels taken from a few thousand aircraft tire tests. Let us choose first a random sampling (Sample #1) of 100, 20 x 4.4 tires. About 9% of this sample were separated. Based on our data to this date, we would consider about 6% of that 9% to be moderately critical, implying that there is a given probability of failure within the life span of the carcass or more specifically, that there is a high probability that the tire would not pass a qualification test. Within this 6%, about 3% of the tires contained one quarter inch or larger separations combined with poor structural uniformity such as non-uniform cord tension or fatigue. On the other hand as a comparison to this sample, the author has observed a group of 300, 20 x 4.4's (Sample #2) in which not one single separation was found. Within this group, probably not more than one to three would fail the basic qualification test for the 20 x 4.4. However, we realize that the indoor qualification wheel test is undoubtedly

more severe than the real world situation. In actual usage, all 300 of these tires would probably have lived out their full carcass lives over two or three R levels without mishap.

A more typical case for 20 x 4.4's would be to find three to five seriously defective tires among a sample of 500, or about 1%. The percentage of critically defective tires in a given sample lot will vary significantly when testing tires manufactured by different companies. In other words, a much more significant variation in data appears when comparing different retreaders. The quality of tires also vary as a function of the date of manufacture.

Next not a more typical random sample (Sample #3) in 30 x 8.8 tires. In this sample, of the 100 tires chosen, only two were separated. And of those two tires, only one had a very high probability of premature failure since critical non-uniformity surrounded the separation.

Our next sample (Sample #4) is of 100 tires, size 40 x 14 – Manufacturer A. In this case, 41% of the tires were seriously defective and rejected, based on a rejection criteria for separations of $\frac{1}{2} \pm \frac{1}{4}$" or larger where the variation, $\frac{1}{4}$", is a function of the overall strength of the carcass or structural uniformity. Most of the separations in the 41% were serious shoulder and/or splice separations. Less concern was given to the separations existing in the center or crown region. The $\pm \frac{1}{4}$" variation was used to single out strong and weak tire carcasses. In other words, a separation as large as three quarters of an inch would be allowed in a tire with a strong carcass, whereas a separation only as large as one quarter of an inch would be allowed in a carcass which was weak and fatigued. We should also note that a few tires in the 41% rejection criteria were rejected solely on the basis of extremely weak and loose carcasses, that is, carcasses containing no separations. We tested a number of these rejects (from the moderately-high-probability-of-failure types to the very-high-probability-of-failure types) on the indoor test wheel and they all, without exception, failed prematurely.

The question: "What do you mean by critical separation?", or "How does one establish an acceptance-rejection criteria?" need to be answered. Acceptance-rejection criteria must be established on a very substantial data base; 100 tires is not substantial enough. After testing over 1000, 40 x 14's, we began to establish a good degree of confidence in terms of an acceptance-rejection criteria, which is $\frac{1}{2} \pm \frac{1}{4}$" where the variation of $\pm \frac{1}{4}$" as mentioned above is a function of the carcass strength. Now let us look at a sample of 100, 49 x 17's. which is Sample #5. Here, 11 tires were rejected. Although in this case we have not looked at enough tires to clearly establish an acceptance-rejection criteria, our general feeling is that separations up to one inch in diameter in the crown area are acceptable for an additional R level as long as the carcass is strong. However, only separations smaller than one quarter inch would be tolerated in the turn-up area or shoulder areas.

Now let us digress momentarily to point out that the seriousness of a separation is established while observing, as a result of repeated tests through many R levels, the propagation rate of the separation as a function of the number of landings. In addition, the propagation of separation as a function of the number of taxi-take off cycles has been studied (the author has studied repeated tests on approximately 27 tires) on indoor test wheels. There is a desperate need for more indoor test data, since we have only scratched the surface of this immensely fruitful area of research. Furthermore, one establishes a very good feeling for how fast a separation propagates by observing from R level to R level how fast the tire is deteriorating both from the point of view of the structural uniformity and the structural integrity (the size of the separation as a function of the number of landings). By observing the increase in size of very small separations from R level to R level, one obtains a feeling or judgment as to how many landings a tire will go through before the separation reaches a size where the tire will fail. We have observed both real world failures (failures on actual aircraft) in addition to failure cases which were simulated on indoor test wheels.

Next let us look at a larger sample (Sample #6) of 40 x 14's – Manufacturer B. In this distribution of 1000 tires, there is a total mixture between R-0's, R-1's, R-2's, henceforth, on up through the R-5 level. The distribution contained more R-2 levels than any other specific level. The rejection over the first 1000 tires based on our data base was 21.5%; however, these rejections were based on both separations and loose splice detail combined with overall cord looseness and tire fatigue. In other words, about 15% ±3% of the total would be considered to be critical. And, in this case, we would define critical as meaning those tires which would have an above average probability of falling had the tire not been rejected prior to the next R level. A special note should be made that many of the tires we observed which contained critical separations were removed from service prior to failure due to cuts, skid burns, etc. Had the tire in the sample been more resistant to cuts, for example, the airline would have experienced even more than the typical one failure per month which was their situation. A brief note should be made that many of the serious shoulder separations which were in structural weak areas were not revealed by air needle injection.

A few additional comments might be in order with regard to the distribution of 100 new 49 x 17 tires. One percent, or one tire, contained a very critical shoulder separation which could have led to a serious problem. Three percent, or three of the tires, contained crown separations with an average size of two inches in diameter. Separations of this size could lead to a problem previous to the next R levels. Five percent, or five tires, contained separations at the turn-up, flipper strip edge, and in the apex strip region above the beads. Another one percent, or one tire,

exhibited very poor cord adhesion characteristics. Upon examining the eleven tires of special concern, we might note that tire #1 contained a crown separation over ½". Tire #2 contained a 1" crown separation. Tire #3 contained a separation in excess of 1" at the turn-up. Tire #4 contained a separation in excess of 1" at the turn-up. Tire #5 exhibited cord socketing to an extent which could lead to a serious problem. Tire #7 contained a 2" separation at the bead apex. Tire #8 contained a 1" separation at the bead apex. Tire #9 contained a separation in excess of 3" in the shoulder. This tire obviously had a high probability of premature failure – and soon. Tire #10 contained a 3" separation at the turn-up. Tire #11 had weak tread adhesion in general. The remaining 89 tires had a very low probability of failure and were excellent candidates for further retreading. It is important to note that all of these 100, 49 x 17's were new R-0's. Throughout the R-0 level, we would consider only one of these above eleven to have a very high probability of failure prior to the next R level; this tire being tire #9, – the one with the 3" separation in the shoulder. Had any of the above eleven tires been overloaded and underinflated at the same time, at least five of the eleven would have had a high probability of premature failure.

Considering R levels beyond R-1, there now is a probability of failure which begins to become noteworthy even under normal loading conditions in tires #10, 3, 7; the tire containing the 3" separation at the turn-up, the tire containing the 1" separation at the turn-up, and the tire containing the 2" separation at the apex.

We should again ask ourselves the question, "What constitutes a critical defect?", that is, a defect which has a very high probability of failure prior to the next R level. And, how does one go about getting data which relates to defect criticality?

Allow me to digress momentarily to say that the beauty of truck tire testing lies in the fact that the data is so much easier to obtain. One simply sorts out defective truck tires from good truck tires, selects several hundred, and then mounts them on trucks in fleets with defective tires running alongside good strong tires to minimize any possible danger of a serious situation occurring. Over ensuing months, and observations of many tire failures, it is easy to establish a clear cut criticality, or acceptance-rejection criteria. Such data can certainly be obtained in a one to two year period in the field, or over a few weeks employing indoor test wheel data.

But, what can one do to establish criticality in the case of aircraft tires? First, one tests a very large number of tires and separates out those which have a lack of structural integrity (separations) and/or lack of structural uniformity (poor construction geometry, loose cord tension, fatigue, low adhesion, etc.). With aircraft tires, we cannot submit them to actual field test runs as in the case of truck tires.

Instead, we must sort out those tires on an indoor test wheel to run them out to failure. After having done so, we must establish the basic rate of propagation as a function of the number of cycles or landings. The obvious problem lies in the fact that real world failure data is nearly impossible to obtain and the gathering of data on an indoor wheel is slow and expensive. One researcher can direct a study on a thousand truck tires in the same period of time it takes to carry out failure analysis on 50 aircraft tires. Further work in this area is critically needed. The best acquisition of data comes through monitoring tires in a typical carrier's fleet. As an example of the monitoring of a given fleet, note tire sample #7 in which 2.6% of a distribution of 2200 tires, size: 46 x 16 were rejected. Here, there existed a clearly defined probability of failure in service had these tires been allowed to remain in service. Note Figure 7 which summarizes the various samples presented thus far.

Before proceeding to a discussion of results on indoor test wheels to establish defect size criticality, it might be inter-

esting to point out that in the case of a 40 x 14 tire, we made a mistake in the early stages of our testing and allowed a tire which contained a 2" separation to get placed into the "tires accepted" category as opposed to the "tires rejected" category. At that time, we were using an acceptance-rejection criteria of ½". That tire, containing a 2" separation, was accidentally mounted on an aircraft *and it failed on the fifth taxi-take off.* We were fortunate in that the failure did not lead to as serious a situation as it could have. As a result of this experience, we believe that a 2" separation would obviously go to failure very quickly.

But what about the case of the ¼", or ½", or ¾" separations? How soon would they fail? Our next step was to take these types of separations to the indoor test wheel and to observe their propagation as a function of the number of cycles. As our first example of the indoor test wheel, we will look at a 40 x 14 - 21 tire and observe the increase in the separation diameter propagation as a function of the number of taxi-take off cycles. In this first case (note

Sample	Size	Quantity Tested	% Rejection	High Prob. of Failure	Lower Prob. of Failure
1	46 x 16	2200	2.6%	1.7%	0.9%
2	20 x 4.4	100	9.0	6.0	3.0
3	20 x 4.4	300	0	0	0
4	30 x 8.8	100	2.0	1.0	1.0
5	40 x 14–A	100	41.0	22 – 25	16 – 19
6	40 x 14–B	1000	21.5	12 – 18	3.5 – 9.5
7	49 x 17[*]	100	11.0	1.0	10.0

FIGURE 7 — Summary of Rejection Rates for Various Sample Tests

*New R-0. All others: R-1 through R-7 with most at or near R-2.

Figure 8), we observed in the original carcass a 7/8" diameter separation. The tire was then mounted on the indoor wheel and after a brief warm-up period, the tire was cycled through five taxi-take off cycles. The tire was then taken off the test wheel, dismounted, and then reholographed. At this time, we observed that the 7/8" diameter separation had grown to 1½" in diameter. The process was repeated for another five taxi-take off cycles and the 1½" diameter separation had now grown up to 6" in diameter. Other separations had grown in diameter which were close to the original 7/8" diameter separation. These separations, as they had grown, had also joined up into the above mentioned 6" diameter separation. Again, a 1/8" diameter separation in this same carcass, which was originally close to the previously mentioned 7/8" diameter separation, grew after five cycles to a 3/4" separation in an additional five taxi-take off cycles up into the 6" separation mentioned earlier. At the same time, an original ½" diameter separation, which was at a further distance from the original two separations mentioned, after five taxi-take off cycles had grown to 1¼". Then after another five taxi-take off cycles had reached out and joined into the above men-

FIGURE 9
U.S. Navy Tire No. 2 — Indoor Test Wheel
40 x 14 - 21

tioned 6" separation. In other words, the original 7/8" diameter, 1/8" diameter, and ½" diameter separation all grew significantly and finally ended up after ten taxi-take off cycles in a single 6" diameter separation which then, in turn, went to failure after six additional cycles.

Let us give an additional example in a 40 x 40 - 21 (Figure 9) aircraft tire. In this tire once again, there was a considerable lack of structural uniformity throughout. In this case, a ½" diameter separation in the original measurement propagated to a 1½" diameter separation after five cycles, which in turn, propagated to a 5½" diameter separation after yet another five cycles. Another original ¼" separation propagated to ½" in diameter after five cycles, which, in turn, propagated to 4" after five more cycles. So, therefore, we note that separations in the ¼" to ½" category propagate quite quickly, particularly when they are in a tire which is structurally weak and/or the separation is in a shoulder region as the above cases were.

FIGURE 8
U.S. Navy Tire No. 1 — Indoor Test Wheel
40 x 14 - 21
Physical Separation versus Taxi-Takeoff Cycles

Figure 10 is an example of an extreme case of separation which existed in a tire removed from an aircraft. The tire

FAILED — 1 cycle

Customer	Tire O.K		Size	House Number
NAVY	Special Study	✔	**40x14/21**	**H59-Nov.**
	Reject			
Mileage	Retread Number		Carrier	Serial Number
5	**R₁₊?**		In	**107x729B**
			Out	
Date Received	Date Shipped		Shipper Number	Holograph Number And Date

FIGURE 10
Indoor Test Wheel Data Extreme Case 40 x 14 - 21

B = bead   S = shoulder   CC — crown center
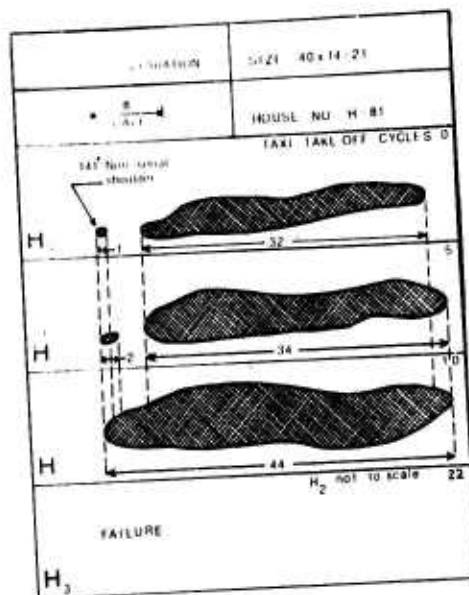
FIGURE 11
U.S. Navy Tire No. 3 — Indoor Test Wheel
40 x 14 - 21
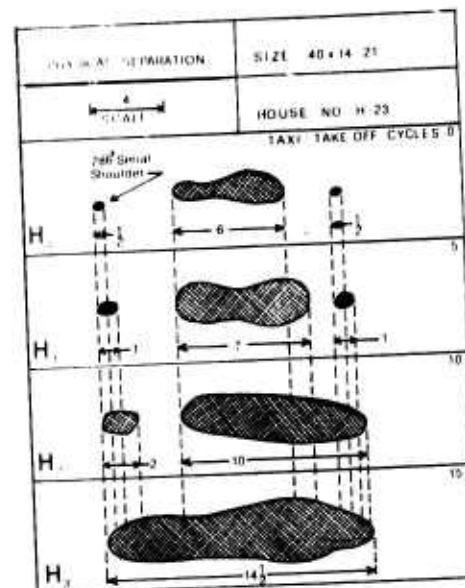
FIGURE 12
U.S. Navy Tire No. 4 — Indoor Test Wheel
40 x 14 - 21
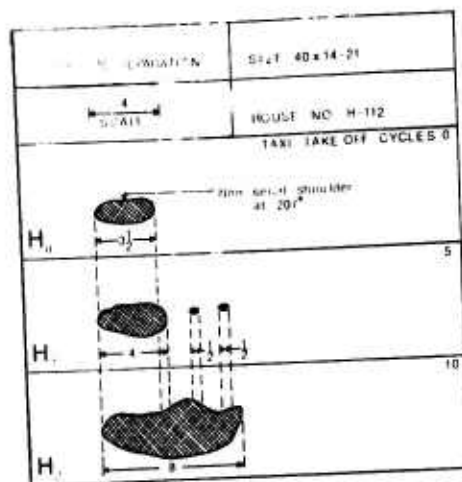
FIGURE 13
U.S. Navy Tire No. 5 — Indoor Test Wheel
40 x 14 - 21
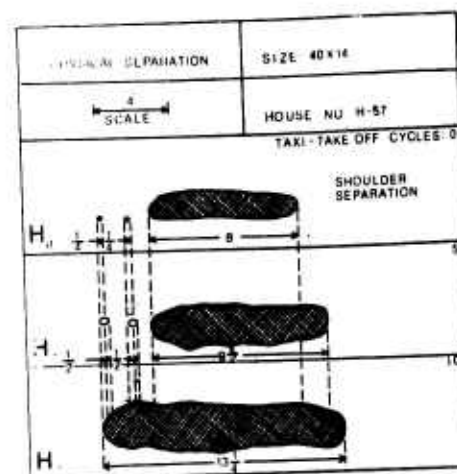
FIGURE 14
U.S. Navy Tire No. 6 — Indoor Test Wheel
40 x 14 - 21

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showed no visible evidence of separation, however its chart in Figure 10 reveals the extent of physical separation on the non-serial side shoulder at the time the tire was first holographed. This tire threw its tread on the indoor test wheel at the start of the second taxi-take off cycles.

Next, note four more realistic examples of propagation in Figures 11 through 14. Figure 11 depicts the propagation of a 1" separation (at 141^0 from the serial number in the non-serial shoulder) and an adjoining 32" separation in the shoulder of an R-4 tire which went to failure in 22 cycles.

Figure 12 depicts the propagation of two small ½" separations and one larger 6" separation which failed after 15, or on the 16th cycle. Figure 13 reveals the amount of propagation which occurred after 10 cycles. The separation originally was a 3½" shoulder separation at 207^0 from the zero degree serial number position. Figure 14 depicts similar propagation after 10 cycles.

Next, allow me to give a dozen examples of propagation of separation in aircraft tires — size 26 x 6.6. Note Figure 15 which is a summary of these examples. In the first 26 x 6.6

TIRE #	NAVY SERIAL NUMBER	SEPARATIONS	CYCLES TO FAILURE
1	4385	2-1/4", 1-3/4"	19
2	000584	2-1"	11
3	1036	1-3/8"	11
4	40170125	weaknesses at 175°, 70°	15
5	9-66-87671	1-3", 1-2", 1-3/4", 1-1/8"	1
6	7-67-0370303OC	1-3/4", 1-1/8"	28
7	1280AK0873	1-3", 14-1/2", 6-1/8", 1-3/4", 11-1", 2- 1-1/2"	10
8	1271AK0680	weakness at 150°	26
9	1031	1-1"	16
10	2115AK0281	7-1/4", 2-1/8", 1-1/2" 1-1", weakness at 22°	10
11	1-66-38474	3-1", 2- 1-1/2"	7
12	02278428	Control Tire — Uniform no separations — Excellent Quality	Did Not Fail

FIGURE 15
U.S. Navy Indoor Test Wheel Data for Twelve 26 x 6.6 — 16 Ply Tires

tire, a ¼" separation at 127° in the crown area of the tire propagated to a ½" separation after five cycles, which in turn propagated to 5/8" after five more cycles, which in turn propagated into a 5" separation after yet another five cycles. An original ¼" separation at 143° propagated to ½" after five cycles, and then propagated to 3/4" after yet five more cycles, and finally propagated into the 5" separation mentioned above after five more cycles. A third separation at 153° in the crown which was ¾" in diameter propagated to 7/8" in five cycles, which in turn propagated to 1" in five additional cycles, which in turn joined into the above mentioned 5" separation. The 5" separation then, in turn, failed after four more cycles. From the above, we note that separations ranging from ¼" to ¾" propagate quite rapidly as a function of the number of cycles. Moreover, these individual separations have propagated this quickly as a result of the fact that they were clustered quite close together. Had these separations been further apart, or had they existed singularly, they would not have propagated as fast. This example provides us with direct information on our ½" separation criteria used by the U.S. Navy. (Present rejection criteria is ½").

Next let us look at an example of a 1" separation in a 26 x 6.6 tire (note Figures 17-A and 17-B). This separation propagated after five cycles into a 2" separation, which, in turn, after five more cycles propagated into a 4" separation which, in turn, propagated to failure at the beginning of the eleventh cycle.

Another description (note Figure 18) is of a 26 x 6.6 tire (#3) which had a very weak carcass, namely, poor structural uniformity. This tire originally had a separation, 3/8" in diameter, which propagated to a 3" separation in five cycles, which in turn, propagated into a 12" separation in five additional cycles, which, in turn, failed before the next cycle was completed. Note that poor structural uniformity has a strong influence on the propagation rate.

Next allow me to provide a brief example of a tire (#4) which showed extreme non-uniformity in weakness throughout the carcass, but contained no separation initially (note Figures 19-A & 19-B). It exhibited the fact that a tire, in this case a new R-0, which had extreme amounts of structural non-uniformity would develop separations very quickly. In this case, after five cycles a ¼" separation

FIGURE 16
U.S. Navy Tire No. 1 – Indoor Test Wheel
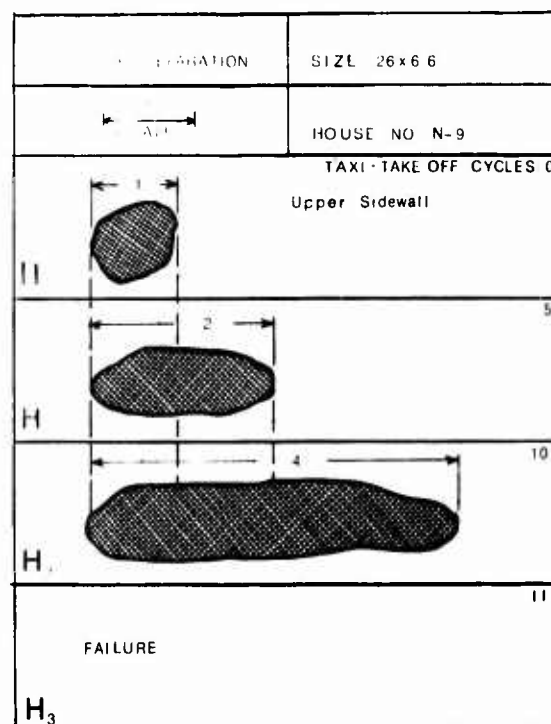
FIGURE 17.a.
U.S. Navy Tire No. 2 – Indoor Test Wheel
Propagation Pattern

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FIGURE 17.b.
U.S. Navy Tire No. 2 — Separation Location & Propagation Chart

FIGURE 19.a.
U.S. Navy Tire No. 4 — Indoor Test Wheel
Propagation Pattern
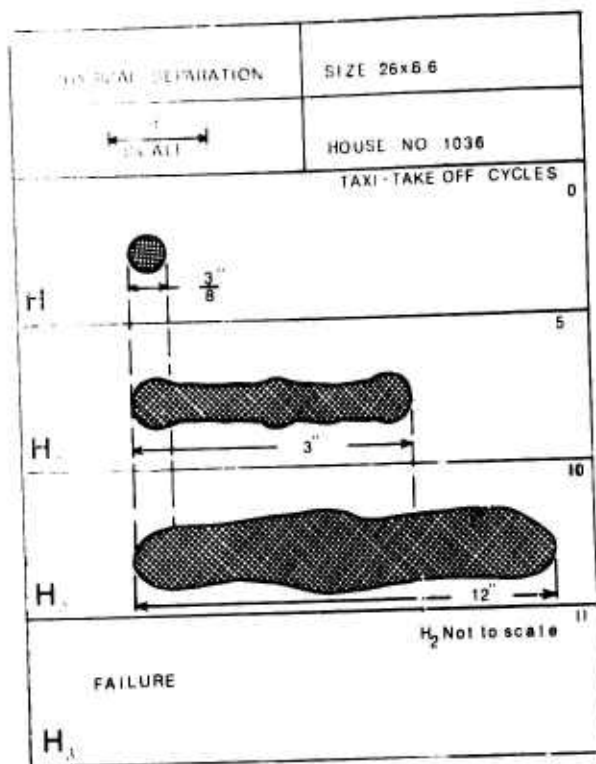
FIGURE 18
U.S. Navy Tire No. 3 — Propagation Pattern

FIGURE 19.b.*
U.S. Navy Tire No. 4 — Separation Location & Propagation Chart
*See page 110 for the reverse side of Figure 19.b.

Notice the separation at 70°, it went from ¼" → 2½" in 5 T.T.'s - unlike truck - very fast - jump transition propagation. Proof that a tire must be tested at each R_n level where n=0, 1, 2, ... n.

Significant propagation, at what size separation will tire fail; propagation is taking place very fast.

Reverse Side of FIGURE 19.b.

evolved at the specific point of non-uniformity. This ¼" separation in turn propagated to a 2½" separation within five additional taxi-take off cycles, which, in turn, propagated to a 20" separation after five additional taxi-take offs.

Figure 20 is another example of structural non-uniformity which progressed to 20" separation within 15 cycles.

Figure 21 is a photograph of the test chart which displays early failure in an R-1 tire (#5). The cross-hatched lines represent a thrown tread which occurred after only one cycle due to the cluster of four separations between 225° and 252° in the center crown region.

Tire #6 is an example of two small separations leading to failure in, as you might expect, a larger number of cycles, namely, 28 (note Figure 15).

Another example of clustering separation can be noted (Tire #7) in Figure 22. Here, you will note that the tread had been thrown, as indicated by the parallel lines across the chart, on the 10th taxi-take off cycle.

Tire #8) (Figure 23), in this sequence, is another example of clustering as related to the geometrical position of the tire's structural integrity.

Tire #9 (note Figure 24) is a straight forward geometrically progressive propagation in a reasonably strong tire.

Figures 25-A and 25-B depict an R-1 tire (#10) with more than the normal amount of separations; however, note how the individual small separations come together to form the 5½" separation at 10 cycles.

Our last propagation example, Tire #11, is again very typical for a reasonably strong 26 x 6.6 carcass, as shown in Figure 26.
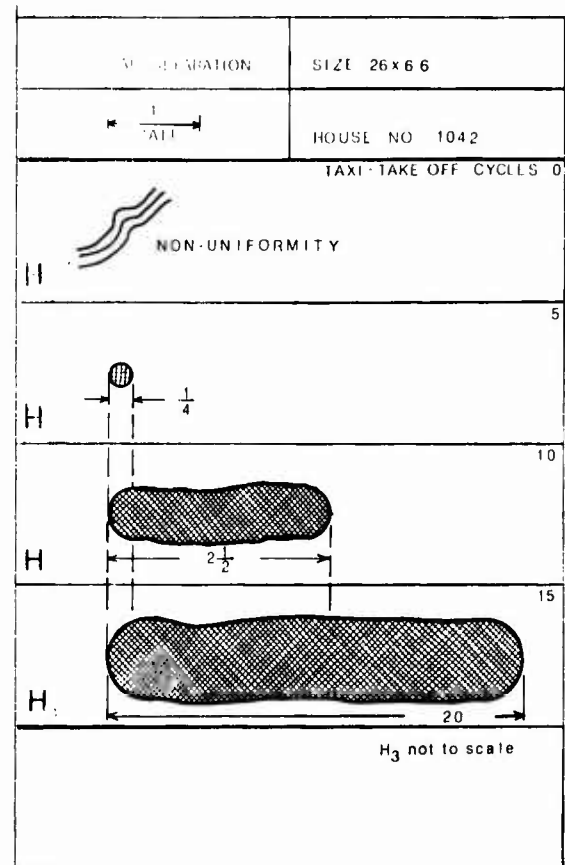
FIGURE 20

U.S. Navy Tire No. 1042 – Indoor Test Wheel Propagation Pattern

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1 cycle — (FAILED) $\Sigma_o - \Sigma_s$

IHI LABORATORY REPORT	Customer	Tire O K	Size	House Number
	NAVY	Special Study ✓	26×6.6	N 5
		Reject		
	Mileage	Retread Number	Carrier	Serial Number
	$H_0 \to$ 5 T.T. $\to H_1$	R_1	In / Out	9-66-87671
	Date Received	Date Shipped	Shipper Number	Holograph Number And Date

Serial No Up

H_a – Navy Early Failure Predicted

B bead   S   shoulder   CC   crown center

FIGURE 21
U.S. Navy Tire No. 5 — Early Failure

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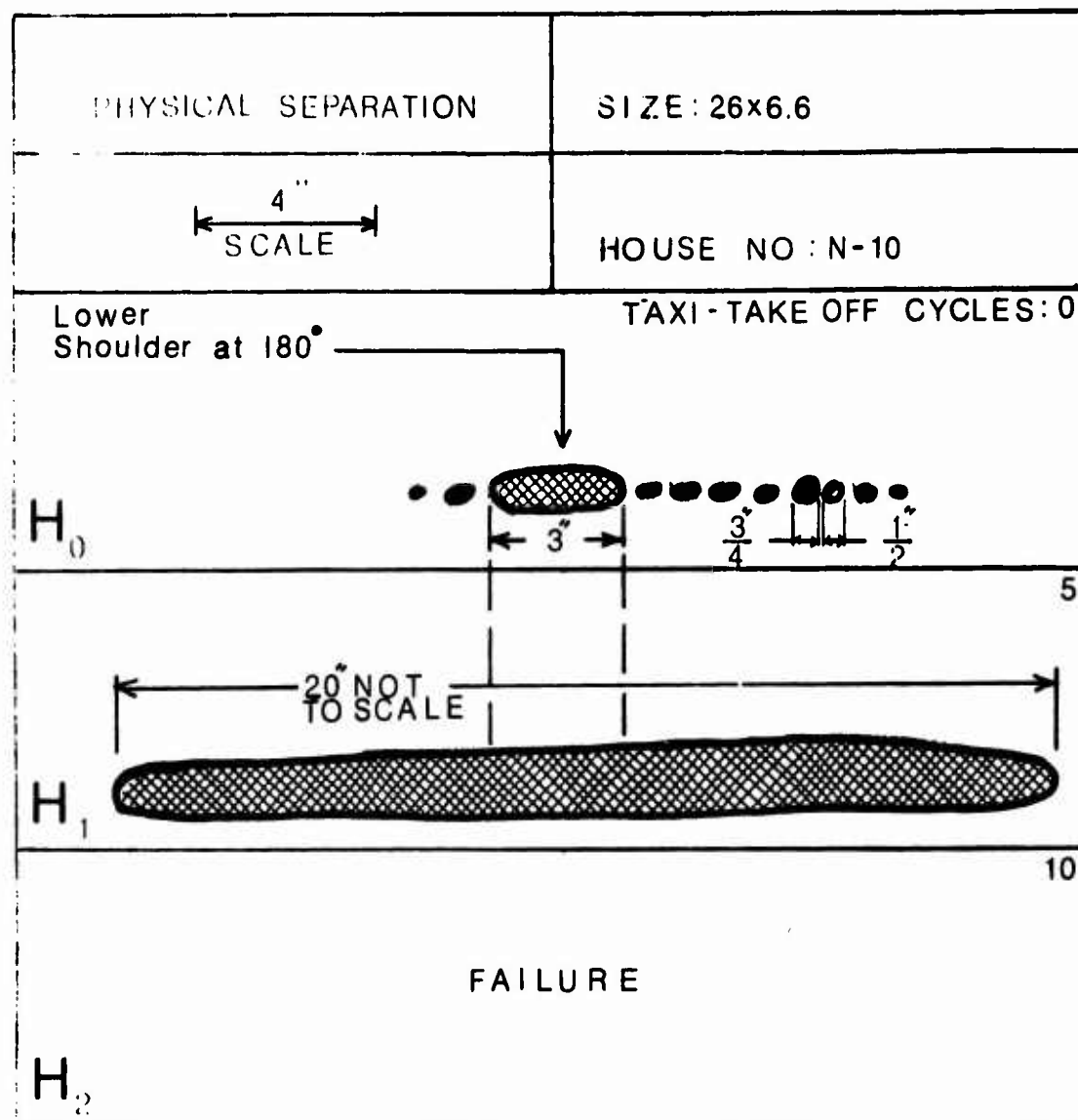
FIGURE 22.a.
U.S. Navy Tire No. 7 — Indoor Test Wheel

FIGURE 22.b.
U.S. Navy Tire No. 7

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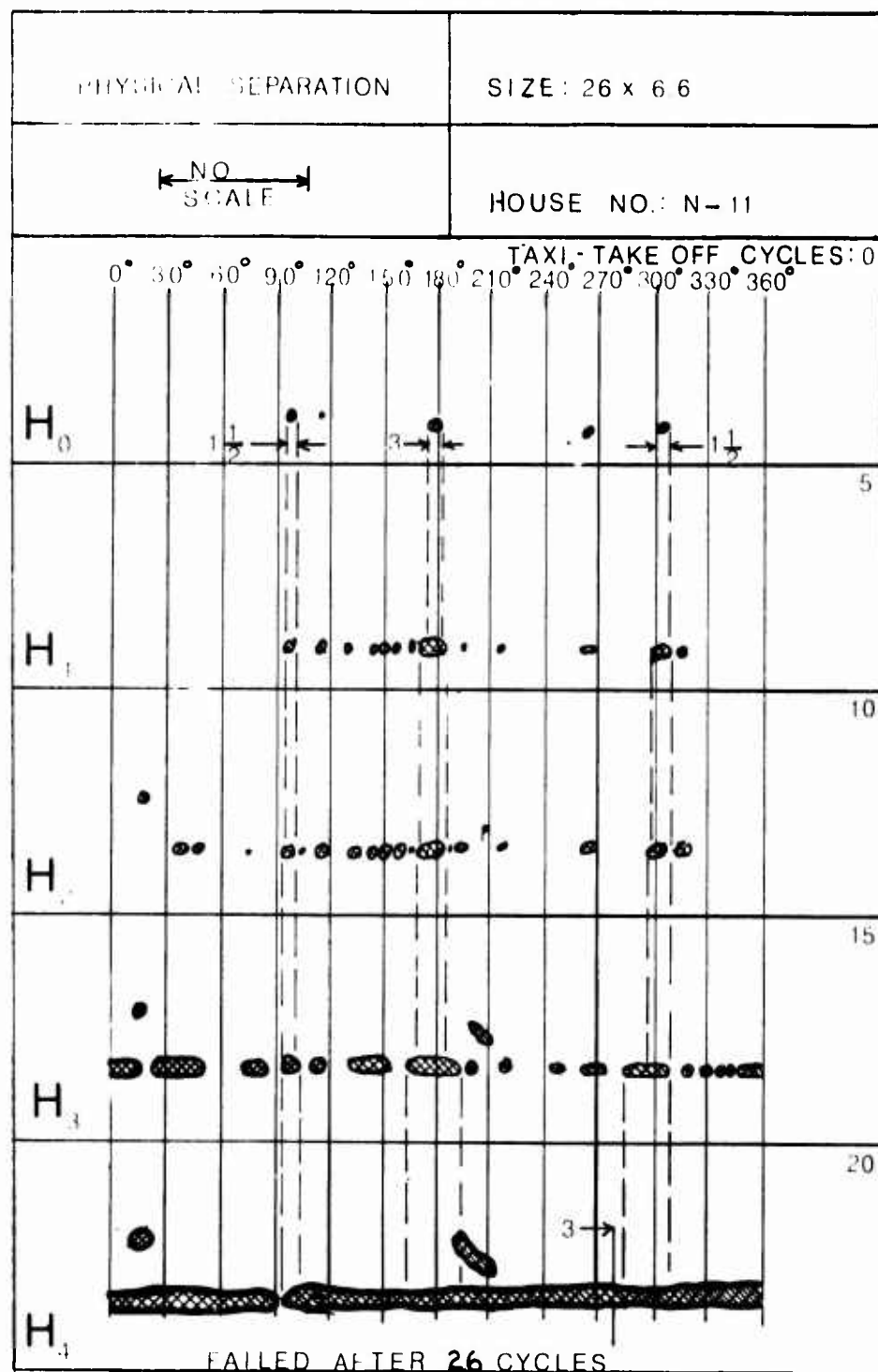
FIGURE 23
U.S. Navy Tire No. 8 — Geometrical Clustering
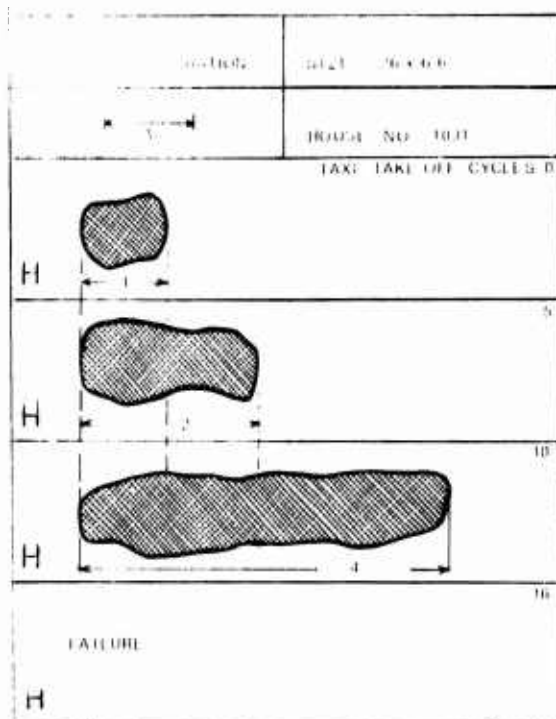
FIGURE 24
U.S. Navy Tire No. 9 —
Typical Geometric Propagation
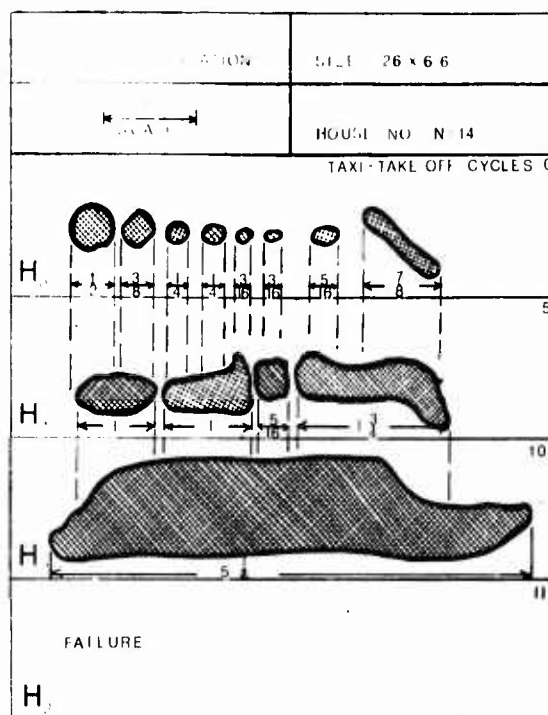
FIGURE 25.a.
U.S. Navy Tire No. 10 — Propagation Pattern

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Failed Σ_0 Σ_5 Σ_{10}

IHI
LABORATORY REPORT

Customer	Tire O K		Size	House Number
NAVY	Special Study	✓	26x6.6	N14
	Reject			
Mileage	Retread Number		Carrier	Serial Number
15 T.T.'s	R₁		In	2115AK02B1
			Out	
Date Received	Date Shipped		Shipper Number	Holograph Number And Date

Serial No Up

B = bead   S = shoulder   CC = crown center

FIGURE 25.b.
U.S. Navy Tire No. 10 — Test Chart

*Not all H₁ data has been inserted due to complex structure.

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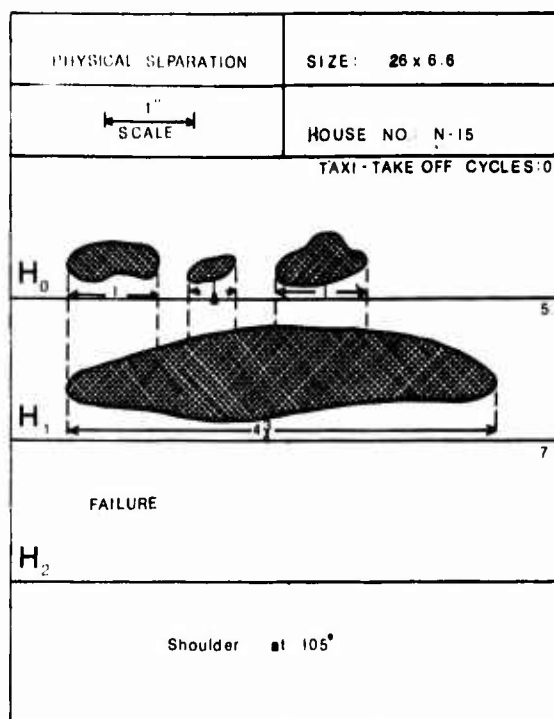
FIGURE 26
U.S. Navy Tire No. 11 – Propagation Pattern

One control tire for this group, Tire #12, which was a strong, structurally uniform tire showed no signs of deterioration after running through the same number of cycles as those discussed above.*

This type of data could be given in greater detail for a large number of examples, but it represents the typical type of information that one obtains on an indoor test wheel. Needless to say, high quality "control tires", observed holographically, ran beside these without mishap. (In a number of cases, as an aside comment, we have predicted the success or failure of tires being sent through conventional qualification tests required by the Navy.) In summary, we can say that when separations exist in a 26 x 6.6 aircraft tire in the size category of ½" $\pm$¼" category, it will go through a significantly larger number of cycles (25 to 50) before it goes to failure if the carcass possesses a high degree of structural uniformity. Digressing momentarily, the author would like to point out that more detailed studies should be carried out on adhesion levels and porosity, which are observable by holographic procedures. Note, for example, the photograph (Figure 27) which is a typical case of heavy porosity caused by undercure as confirmed after the hologram was taken by cutting the tire's center crown.

On the other hand, note Figure 28, which reveals via the holographic pattern a reduced adhesion level in two regions of the tire. These regions were caused by a latex based marking substance which was not absorbed by the com-

*In future test work, a larger number of high quality test tires should be run out to failure.
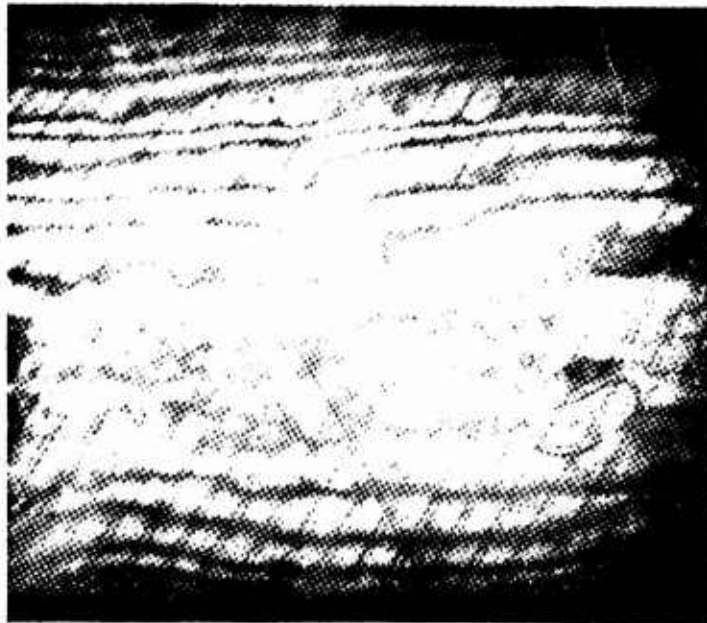

FIGURE 27
Pososity in Center Crown Region

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FIGURE 28.a.
Holographic Pattern Revealing Low Adhestion
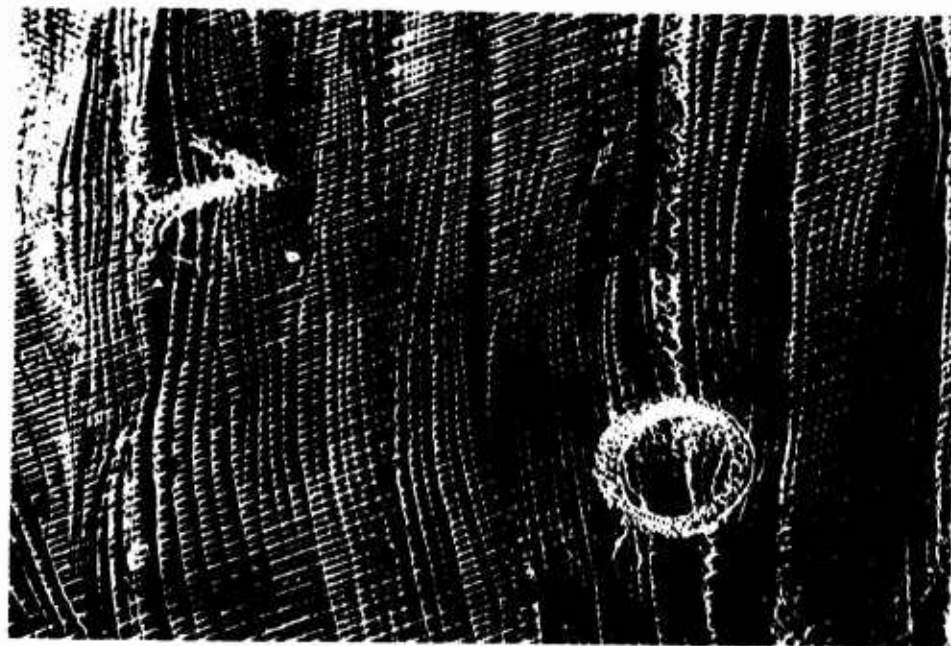— Courtesy of C. Hoff, B. F. Goodrich

FIGURE 28.b.
Physical Tire Dissection — Tread to Carcass rubber surface revealing
latex based marking substance which reduces adhesion levels.

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pound (marking substance used to record date codes on the fabric). Note the reverse number "20" which resulted in lower, "non physically separated", adhesion levels as revealed by the physical sample shown.

Before proceeding, mention should be made about the percentage of rejections as a function of a given R level for commercial aircraft tires. We have found throughout our statistics that roughly speaking the same percentage of rejections, plus or minus 10%, take place at each R level in large distributions of 40 x 14 - 21 aircraft tires. This data would suggest that separations are appearing at each R level at about the same rate. Separations continue to appear as the cords loosen up and general fatigue sets in. Much of the data which we have observed to date in 40 x 14's would suggest that one would be wise not to make the decision to reject a tire based on a given R level. It would appear to be a much wiser criteria to decide on the life of a tire based on the number of cycles or landings it goes through rather than the number of R levels. This is the data which must be obtained in the future. We strongly feel at this time that once an understanding is obtained of the degradation of a carcass as a function of the number of landings that decisions should be made wherein a tire is allowed to stay on an aircraft as a function of the number of landings and not as a function of the number of R levels. It is conceivable that a tire with an R level of, for example 5 or 6, could have significantly less landings on it than another tire which is only an R-2 or R-3. This could partially explain the reason why we sometimes see less fatigue in an R-5 or R-6 than we might in an R-3 or R-4.

Next we note in terms of failure mechanism characteristics of a given tire construction that the small separations propagate very slowly if they are in a very strong tire and that these separations will propagate out through a number of landings before the background carcass begins to weaken, to loosen up, and then go to terminal failure over a fairly short number of landings. Now let us compare the above notation very briefly to truck tires whose separation propagation rates are well behaved. If we were to look at separation size as a function of mileage and draw a graph for truck tire data, we would notice that it would fall very nicely along a given line. In general, the relationship between separation size and mileage is a linear function with the variation in slope of that line being determined by the overall strength of the tire. In the case of truck tires, we then have a band of linear traces whose milder slope represents tires which are quite strong. Those linear traces with a stronger or higher slope represent tires which are weaker.

When measuring aircraft tires, we think in terms of the number of taxi-take off cycles versus separation size. Here, we notice that a small separation will typically propagate in a strong tire slowly wherein the curve along which it travels (that is the separation diameter as a function of cycles) will look very much like the truck tire case. After many cycles, and after the carcass has begun to fatigue and

loosen up, there will be an increase in separation size as a function of cycles which will increase exponentially to the terminal failure point. In a tire which has a very weak carcass, we will note that the separation size will increase exponentially as a function of the number of cycles in very early stages, whereas mentioned above, the separation size as a function of a number of cycles will increase linearly with a very mild slope for a long period of time and will then rise exponentially in a strong tire. As mentioned earlier, the cardinal difference between truck tires and aircraft tires is the following point. Almost without exception, all separations or areas with a high probability of separation will be observed in the original carcass at the time the tire is new. Even after the tire has been retreaded new separations are unlikely to appear in a radial truck tire unless they are the result of mistakes the retreader has made. New separations which are specifically a function of the carcasses themselves do not appear at these later stages. Conversely, in the case of aircraft tires, the separations which are observed at various periods during the life of a given aircraft tire carcass seldom appear when the tire is new or straight out of the mold. As a matter of fact, on the average, rarely does one see in new aircraft tires more than 1% or 2% which are separated. On the other hand, after a number of cycles, perhaps 1000 landings which may be at a R-5 level, one might note a number of separations in a given tire carcass which did not appear either at the early stage of the tire's life, or in the previous R level. In other words, separations continue to form and propagate (note Figure 29) at a variety of stages throughout an aircraft tire's life (throughout each of its R level stages). It is not uncommon to see no separation in a R-0 level of a given tire, or its R-1 level, or its R-2 level and on up to some R-n level whereupon separations will appear over a very short period of time and with great profusion. When establishing acceptance-rejection criteria, this would lead one to the conclusion that aircraft tires must:

(A) be studied to determine the type and location of separation which will form and the average rate of propagation of these separations. The rate of propagation is by far the most significant parameter for a given tire.

(B) be studied to determine the type of failure mechanism which is given construction experiences. Furthermore, it is evident that the tire must be tested intermittently after a given number of landings. In the case of 40 x 14 - 21, the number of landings associated with a given R level, for example from R-1 to R-2 in a typical DC-9 operation, turns out to be just about the ideal spacing for the frequency of testing.

(C) be studied by holography before and after each R level to determine the optimum number of landings for a given size, construction and manufacturer. In the future, this test time can be
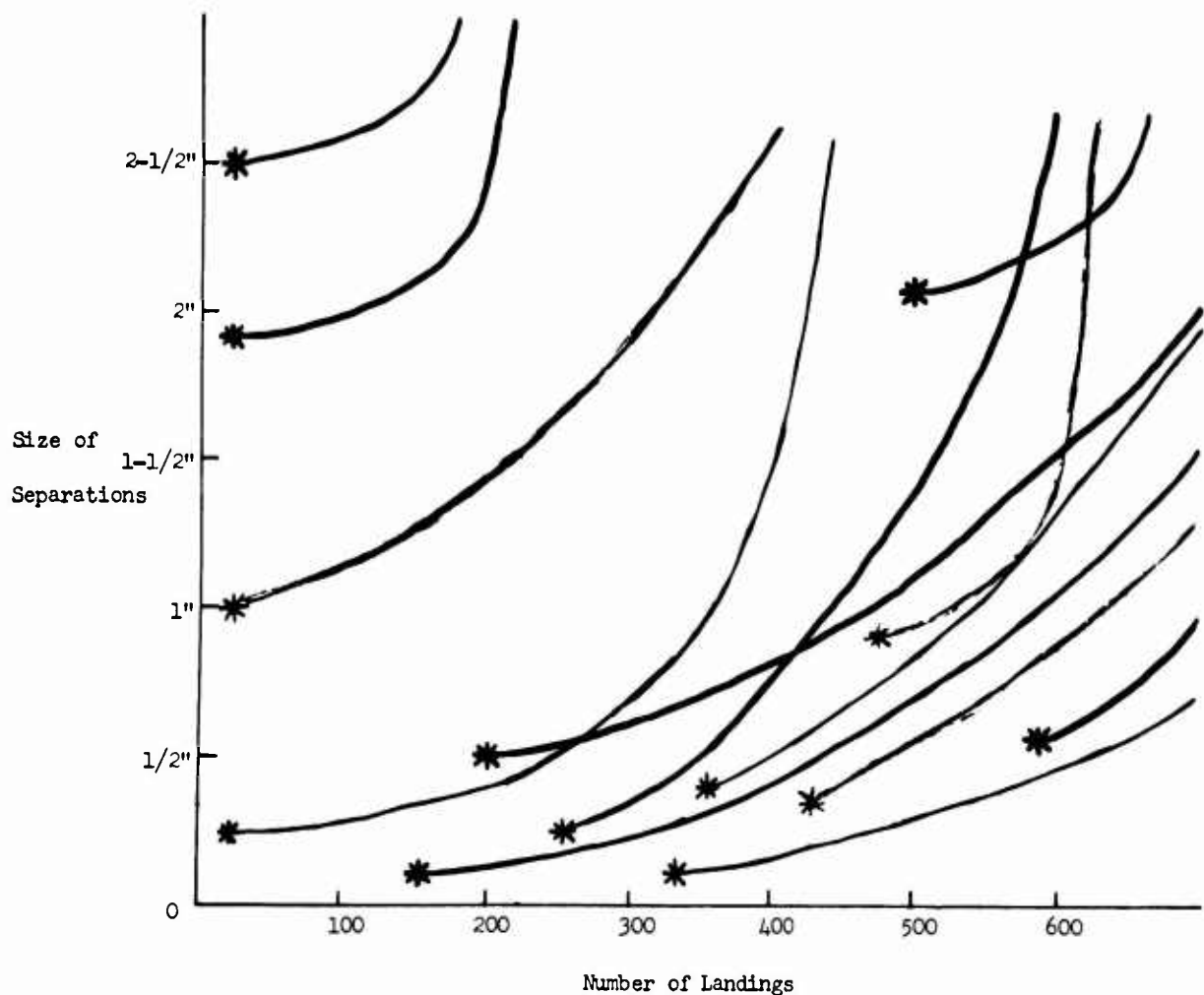
FIGURE 29
General Separation Propagation Behavior As a Function of the Number of Landings

established as a function of the number of landings a tire experiences, provided that the inflation pressure has been maintained throughout the period under consideration. Note: Underinflation will significantly increase the propagation rate of separations. If a tire reaches an established number of landings, it should be retested prior to further use.

The following information is the result of our first commercial carrier studies which were carried out over the past two years. This carrier was experiencing approximately one tire failure per month over a one year period with an average cost per failure (amortized over the year) ranging between $20,000 and $25,000, due to structural damage to the aircraft and rubber ingestions in the engines. Over a

relatively short period of time, all the tires in service of a given type were holographically tested and all tires with separations greater than one-half inch in diameter were rejected. Since the tires with separation over one-half inch were taken out of the systems, no tire failures were experienced over the following two years. It is important to note that this type of testing will not eliminate all tire failures, but it can significantly reduce the incidence of failure which has been dramatically proven in more than one airline. It is interesting to note that the original rejection rate in the above case was slightly over 20%, whereas after culling out the tires containing separations over one-half inch in diameter, the rejection rate fell to around 12%. Further analysis has revealed that larger separations can be tolerated in the crown area which puts the rejection rate under 10%.

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Now to summarize. The basic objective of this paper has been to comment upon the meaning of separations in aircraft tires. You can look at sizable distributions of tires and discover that large distributions of tires have very low incidences of separation — at times as low as 1%. Then we will note other case histories where the percentages can get significantly over 10%. Our basic objective at this time is to understand more thoroughly the background strength criteria in aircraft tires and to establish an acceptance-rejection criteria based on a fairly large data base. In general, we would like to test 1000 tires in a distribution and then cull out those tires which have separations. The tires pulled out must be evaluated to determine separate propagation rates as a function of structural uniformity. Acceptance-rejection rates should then be established and then routine testing of the tires should be carried out at each R level where the R level does not exceed a given number of landings for a given tire size and construction. It has been said, "Well, you see most separations in retreaded tires; you don't see many of them in new tires." This is a misleading statement. Although separation typically does not exhibit itself until an advanced stage in a tire's life, the original construction and the care with which the original tire is built has a significant impact on the amount of separations which will appear in the tire's later life. Needless to say, we find that retreading practices are not often the cause of separation in aircraft tires.

It is only going to be with the greatest of effort and patience that the separation propagation rates and basic failure mechanisms are understood whereupon realistic acceptance-rejection requirements can be placed on a given tire despite the fact that relatively few tires contain separation. Although all tires experience fatigue as a function of usage which—if the tire is used long enough—will, in turn, eventually lead to separation. The general per-performance of the typical aircraft tire far exceeds that of most typical engineering systems. Aircraft tires perform an extraordinary job in terms of the requirements that are placed upon them and the abuse given to them. With modest effort, great improvements can be made in aircraft tires at relatively low costs resulting in an example of one of the most impressive engineering systems of our day— namely, the typical aircraft tire.

Through the use of holographic testing, tire failure, which can result in expensive aircraft damage, can be reduced. The cost of these tests are relatively small as compared to the potential savings brought about by reduced failure incidence. Moreover, high quality tire carcasses can be used for a larger number of total landings than was previously realized.

EXPERIENCE WITH TIRE DEGRADATION
MONITOR IN COMMERCIAL APPLICATION

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Experience with the TDM (Tire Degradation Monitor) in Commercial Applications

Several years ago at the Second Symposium on NDT of tires in Atlanta GARD and the U.S. Army[1] presented the first of our results on ultrasonic testing of tires. That presentation gave the description of the genesis of the tire degradation concept and road test results that verified the concept with military tires. Bob Watts of TARADCOM will in a later paper at this symposium present a more detailed look at the Army program—past, present, and future. Again at the Third Symposium we provided updated results of testing of the degradation concept and associated tire research. Now at the Fourth Symposium we are going to present our further experience since the Third. I am going to emphasize the commercial use of the TDM and Bob Watts will talk about the military use.

First I feel it is appropriate to review the concept of tire degradation and its development. The original intent of our Army sponsored research program was to develop a NDT means of inspecting tire casings prior to retreading. We concentrated on ultrasonics because of its potential for speed, automation, sensitivity, and low operating costs. We looked at two basic approaches: through-transmission and pulse-echo.

The through-transmission had a number of potentially significant advantages. It was air-coupled (no direct contact with the tire would be needed) and it operated at a frequency (25 - 40 KHz) which seemed to be good for the size of defects of interest. It has one serious technical drawback which in the end dictated against its use. That is an inability to know the distance to the defect. Thus, a tread lift or separation looks the same as a ply separation; patches can look like separations; a nail hole in the tread rubber may look like it penetrates the body; and cuts in the tread will look like cuts in the plies. The lack of distance information is the fundamental reason why we dropped further research with the air-coupled through-transmission technique in favor of water-coupled pulse-echo.

Water coupled pulse-echo has two fundamental advantages: sensitivity and distance information. Its fundamental disadvantage is that it needs to be directly coupled into the object of inspection. The direct coupling generally is done through a liquid medium (in our case, water or a water soluble compound). Our first attempt was a 360° scanning machine shown in Figure 1. (We have built two of these machines and both are currently in use at Army Retread Depots.) We scan the crown and shoulder areas of each tire.
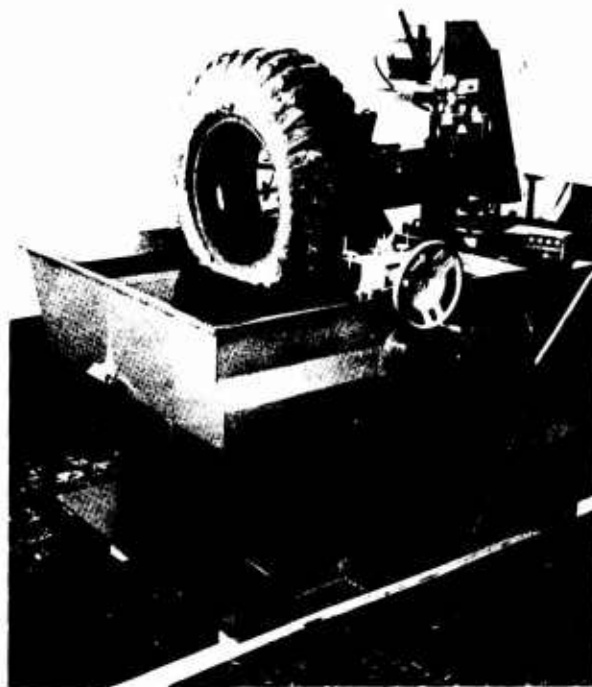

FIGURE 1
TIRE SCANNING MACHINE

After completion of a rather extensive (500 tires) program of tire inspection with the UT scan system and in conjunction with other tire research we developed a rather unique

1. "Ultrasonic Tire Inspector", Gamache and Kraska, Proceedings of the Second Symposium on NDT of Tires, NTIAC 75-1.

concept of a fundamental mode of tire failure—degradation. Our research indicated that as a tire was run its background ultrasonic character would continuously change until a failure occurred (Figures 2 and 3). We correlated this change first with a reduction in cord and peel strength and finally with road test failure.

We hypothesize that as a tire rolls and is fatigued in service the cord structure begins to break down—particularly in the outer plies. In a steel-belted tire the cords are basically inextensible and the break-down occurs typically between the steel belts and the body plies. (In fact even in fabric-belted radial tires this seems to be true—thus giving rise to the common belt-edge separation.) Retreaders know this degradation by the term "casing fatigue" and see it also as casing growth or stretching on fabric tires. A number of other different researchers have apparently observed this phenomenon without realizing it. It can be seen as exces-
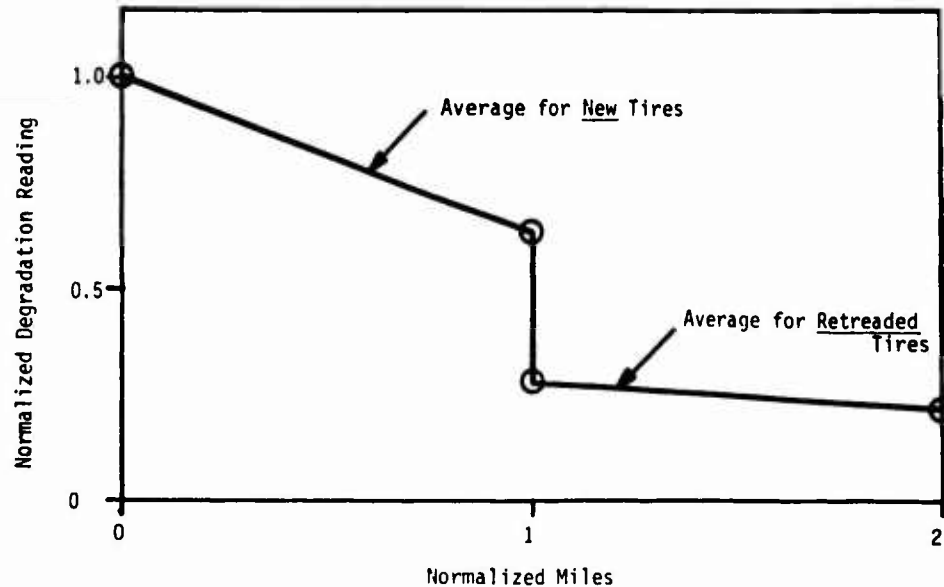
FIGURE 2
POPULATION DEGRADATION READINGS
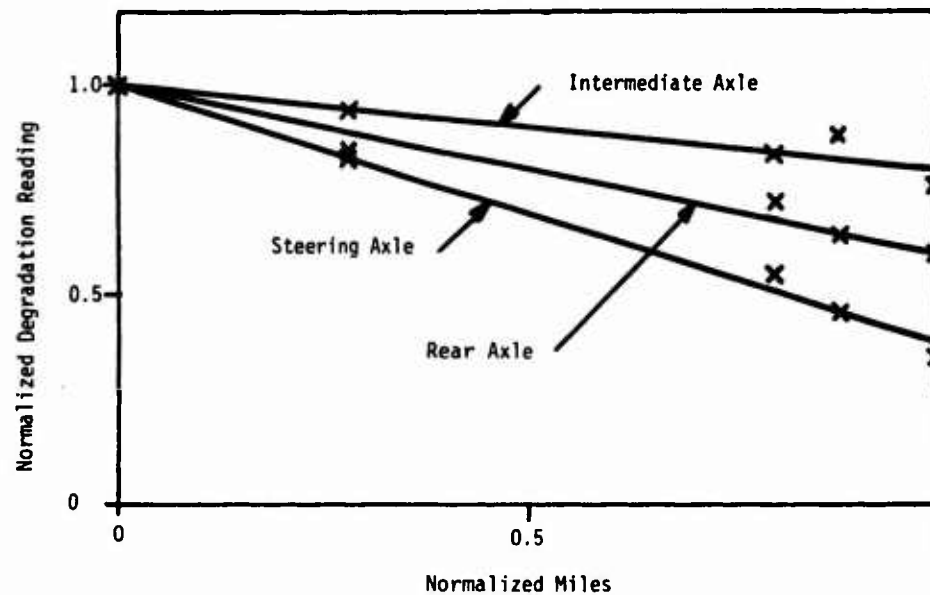
FIGURE 3
ON-VEHICLE DEGRADATION READINGS

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DIGITAL DISPLAY ⌐ LOCAL DEFECT INDICATOR

GATX

CASING QUALITY

TDM

PROBE
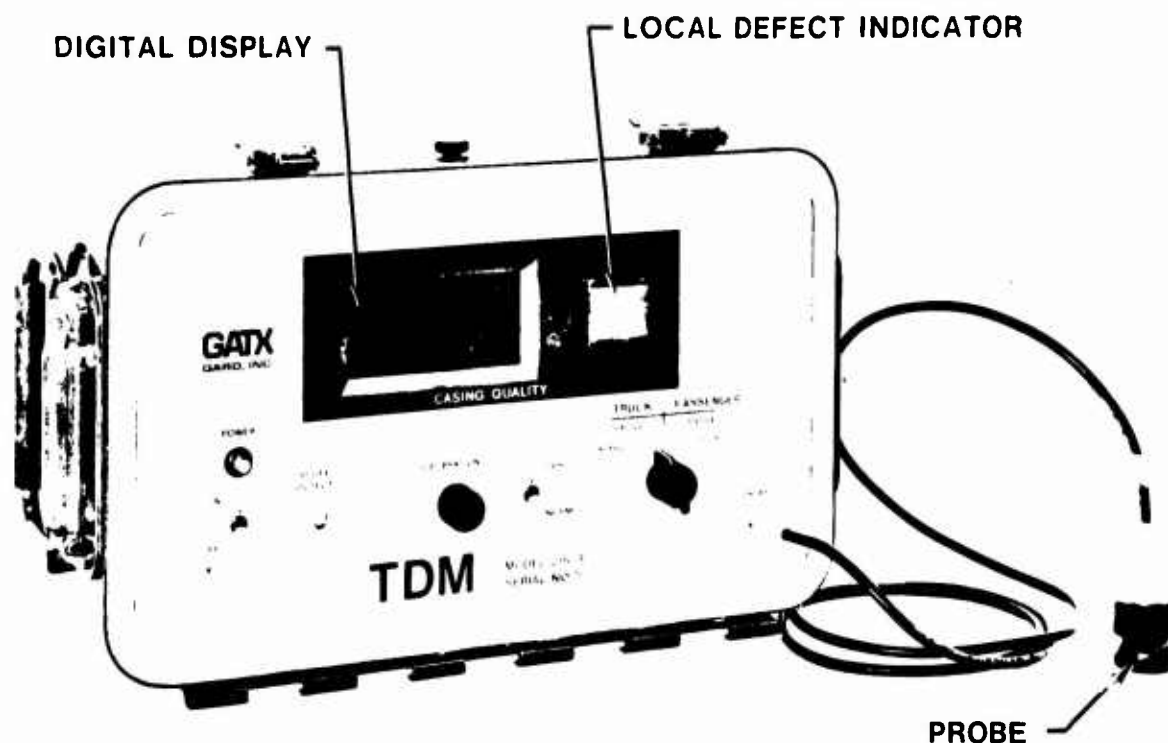
FIGURE 4
TIRE DEGRADATION MONITOR

sive attenuation in air-coupled UT, excessive absorption of air or radioactive gas in variations of the air needle injection test, and a fringe waviness in holography.

The fact that the UT degradation measurement correlated well with road test failure led GARD to develop and intro- duce the TDM (Tire Degradation Monitor) as a simple eco- nomical means of estimating residual casing life prior to retreading. The commercial version is shown in Figure 4. Selling the UT concept to an industry that until this time has not really utilized ultrasonics has been a difficult task. First there is an expectation that if an NDT device is to be of value it must cure all problems at once—which, of course, no NDT device is going to be able to do on a structure as complex as a tire. Secondly, it is expected to be totally fool-proof as the industry apparently feels it has almost no control over its work force. And lastly, it must be very in- expensive.

Surprisingly, we feel that the TDM comes close to doing all of these things—except find every type of tire defect. Still it has been a slow education effort that is beginning to show a number of excellent results. This is a tribute to the people who have bought a TDM, devoted some time to learning its operating principles and how to use it. We have

found that the users who made an effort to understand the TDM and use it on a consistent basis have a very high regard for its usefulness and value. Those people that dabble at it get very confused and are less convinced of its value. For our part we underestimated the time it would take for people to become used to using the TDM and the general need felt by our customers for the CRT presentation of the signal in addition to the digital display. Small inexpensive, ($400) readily available scopes can be used and have been supplied to most of our customers (the others supplied their own scopes).

The main intent of this paper is to acquaint the tire industry with some of the commercial applications to which the TDM has been put and this I will now do.

One of our earliest applications was inspection of nylon truck tires for undercure. Undercure in a new or "hot- cap" type of retread is generally indicated by porosity for- mation in the shoulders (Figure 5). The TDM used with a scope can be used to detect this porosity and hence under- cure. Figure 6 shows photographs of the scope traces for both properly cured and undercured tires. The signals at the far right of the undercure trace indicate porosity where- as normal tires are clear in this area. All of this inspection
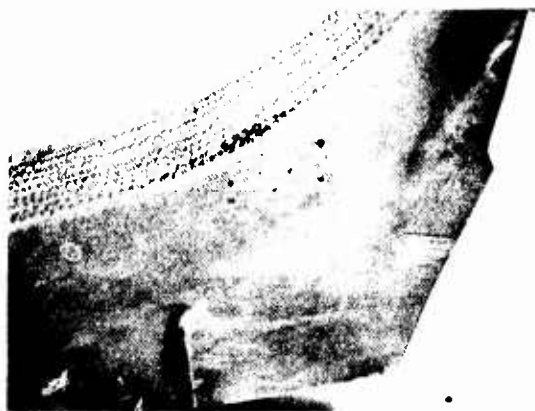
125

a. Normal Tire Cure
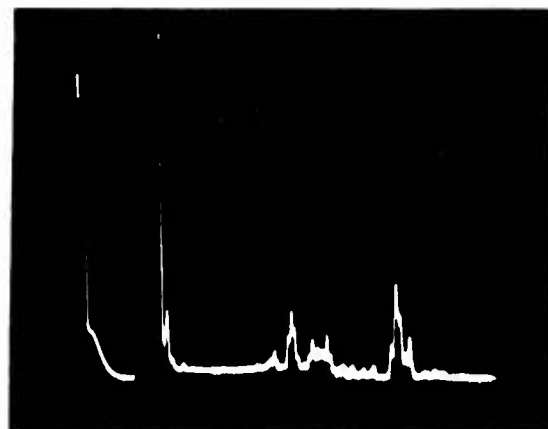
FIGURE 5
CROSS-SECTION OF UNDERCURED TIRE

was done from the shoulder. The digital display is not used. Figure 7 shows inspection being performed in the tire plant. Note that tires are being inspected in stacks so that tire handling is minimized. This capability is unique to pulse-echo ultrasonics. The result of our inspection of approximately 700 tires was that approximately 70 undercured tires were found which agreed well with the manufacturer's expectation. The alternatives would have been very expensive radiography or scrapage of the whole lot of tires. Estimated cost savings: $4000 up to $70,000 depending upon ability of radiography to see minor porosity in truck tires.

Two of our earliest sales of production units went to two Bandag dealers: American Bandag of Libertyville, Illinois and Weirton Bandag of Weirton, W. Virginia. American inspects all incoming casings with the TDM for grading and sorting. Originally they followed our suggested guidelines (Figure 8) which initially caused distribution of tires as shown on Figure 9. As American has gotten more experience they have instituted a much more complex disposition procedure. Their current disposition grading scheme considers such things as customer (end use), size, tire construction, and tread thickness to be applied to the tire. The TDM readings are the key to this scheme and are recorded in the tire invoices, and stored in their warehouse computer memory records for future data analysis.

An example of the system's usefulness came when one customer complained of top ply separations after only several thousand miles of running. Knowing that the tires had been graded and had been selected to be good casings for drive wheel use, the plant manager, John Nelson, looked
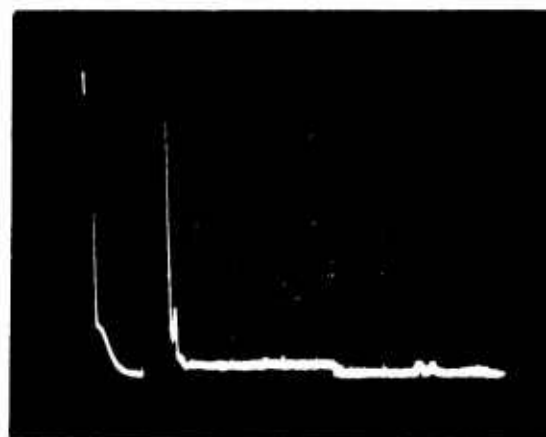
b. Undercure

FIGURE 6
SCOPE TRACE – UNDERCURED TIRE

either for processing or use errors. It turned out that the customer had used the tires on single drive-axle tractors which apply a great deal of torque to the drive tires. American backed off to a lighter tread to minimize heating and flexing problems and has had no further complaints from the customer. In the pre-TDM days there would have been a considerable tendency to blame the casings until a great many failures had occurred. Another example of use is on steel radial truck tires. They had prior to TDM use experienced a large number of retread failures of tires from one manufacturer. They (and a number of other retreaders) were about to put a halt to retreading of that type of tire when they started to examine the tires with the TDM. A

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FIGURE 7
TDM INSPECTION IN PLANT

TYPICAL TDM CLASSIFICATION

(TRUCK TIRES)

TDM Reading Range	Disposition of Casing
0-1	Reject
2-4	Trailer Use Only
5-16	Any Use
17-25	Trailer Use Only
Erratic	Trailer Use Only
Red Light	Trailer Use/No Warranty

FIGURE 8

INSPECTED TIRES

DISPOSITION	DISTRIBUTION %
Reject*	4
Trailer Use	46
Any Use	50

* This rejection is before normal

visual inspection

FIGURE 9

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great many of the tires were found to give a very high reading. (Such tires are called "red-light" tires because the reflected signal is so high as to trigger the separation indication light.) American held back the "red-light" tires and retreaded the rest with their heaviest tread. Result: no further failures of these tires.

"Red-light" tires are a small but significant portion of the tires that come into American. Certain classes of these tires have been found to be non-retreadable, while others seem usable for light duty use. At first some customers complained about holding out tires based upon TDM readings, but most have become convinced about or at least accept this procedure. An adjustment avoided by the retreader is a down-time incident avoided by the vehicle owner—both save money.

American says they will not retread tires without a TDM inspection. They have inspected almost 20,000 tires with the TDM, and have it running 8 to 10 hours per day. After some early electronic "bugs" were corrected, reliability has been 100%. The use of the TDM and other on-going quality control improvements have reduced adjustments from near 5.6% two years ago from all causes down to 1.8% currently with records being kept by computer—not based upon general impressions. The 1.8% figure is very good while maintaining a very high rate of casing utilization (80%) and is a good customer selling point. Their John Nelson says that while he can not develop an exact savings produced by the TDM it has greatly more than paid for the cost of the TDM and that they would not be without it.

Weirton Bandag does not use this machine on an every tire basis, because as R. Rock, Retread Foreman, says: "We learned so much about visual tire inspection the first two months we had the TDM, I feel we do not need it for normal use because we can fairly accurately guess the TDM reading". They now use the TDM only on questionable tires, but very much believe in the TDM and the degradation concept. They too have moved away from the original grading scheme to one tailored to each of their customers unique requirements. They too have shown customers that certain manufacturers or types of "red-light" tires can not be retreaded even though visually the tires look perfectly good. (The high level UT reflection is generally from the first ply or the bond between the undertread rubber and the tread rubber. In many cases we have found a layer of microporosity to be the reflection; but in others we still do not know what causes this very high reflection. It should be the topic of some very interesting research.)

In a test run by a major rubber company 16 pairs of matched retreads were road-tested on trailers. One tire in each pair had a TDM reading of 3 or less and the other had a reading of 4-15. The results were that 80% of the low reading tires failed during the test while only 20% of the moderate reading tires failed. Further testing on dynamometers has not shown such consistent results; but it is our feeling that degradation failures are not well simulated on wheel tests because wheel tests do not duplicate the random fatigue loads that tires see in service. (Aircraft manufacturers have found, for example, that metal behavior under random loading is considerable different than under a uniform cyclic load.) We recommend using road tests.

A number of interesting uses have been developed using the TDM as a quality control device. The major rubber companies, large retailers, and consultants have been active in this area. The use of the TDM to detect undercure in truck tires was mentioned earlier, but it has also been shown to work well on passenger tires as well (using shoulder inspection and a scope). One rubber company is using the TDM as a means of checking for undercure and microporosity in one of their retread plants. Searching for microporosity one generally uses the scope although an experienced operator can probably do it with the digital display only. Figure 10 shows a schematic of what one would expect to see in the scope trace to find undercure. Figure 11 shows some actual scope traces of microporosity (as noted by indication of a poor retread bond line) versus no microporosity layer in a good retread bond.

Another rubber company has been using the TDM to monitor the development of belt-edge separations in aramid tires. The tires are checked every 2000 miles of road testing. They are inspected in the shoulder (at the belt edge) and the crown using the scope. The development of shoulder separation has been shown to coincide with changes of the tire monitored in the crown. It is our feeling that this
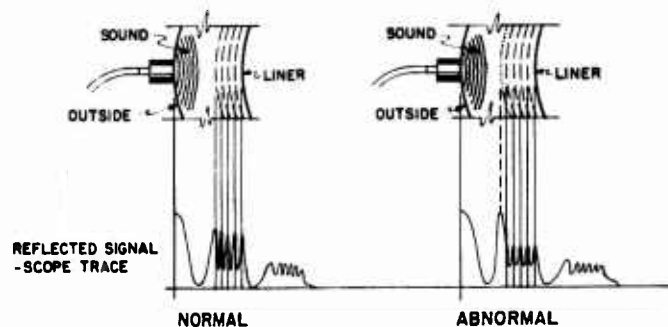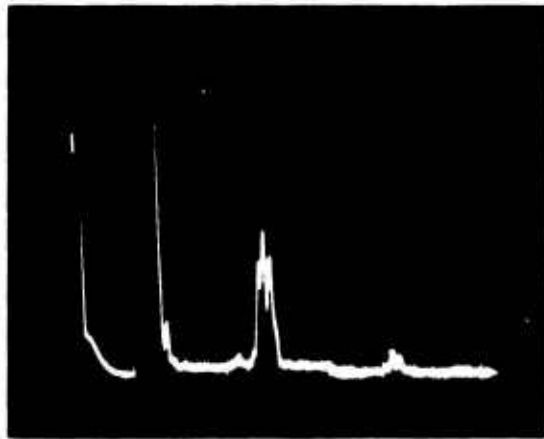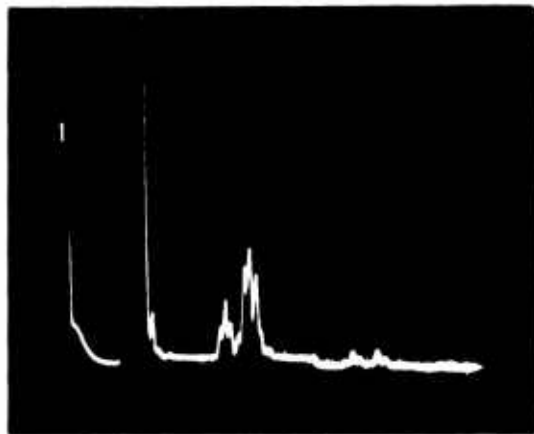

FIGURE 10
COMPARISON OF NORMAL TIRE ULTRASONIC
SIGNATURE WITH INCORRECT TIRE –
UNDERTREAD MICRO-POROSITY

a. Normal Tire

b. Bad Bond · Mircoporosity

FIGURE 11
TDM DISPLAY OF MICROPOROSITY

agrees with our earlier studies of radials in which failure occurs in the area between the belts and the body plies. How this change would be expected to look for steel radials is shown in Figure 12. The signal from the belt plies remain constant, while the signals from the body plies change. The radial setting on the TDM is set to read in this area and monitor this change, but the scope should be used to check to see that the gate reads in the correct location for differing types of tires.

A series of tests[1] performed on the West Coast on a fleet using radials also yielded information on belt-edge separations. In this case the inspection was done in the shoulder area because sectioning showed that the belt edge was

directly underneath the outer rib and the surface plane was parallel to the plane of the plies at that point. Belt-edge separation caused a reflection to appear between the body and belt plies and a drop of reflection from the liner. Destructive sectioning of the tires indicated a 100% agreement between ultrasonic prediction and existence of separations. Partially as a result of these tests the fleet owner made a change of tire supplier (a multimillion dollar contract).

We performed some laboratory work on belt-edge separation detection and have shown it to be feasible. The key problem is knowing the location of the belt edges or developing a correlation between between edge behavior and changes in the crown. It would seem that one gets beyond manufacturing causes of belt-edge separation, separations at the belt edges ought to be indicated elsewhere, and measurements elsewhere should lead to prediction of belt-edge separations such as in the case of the aramid tires.

Another use of the TDM in quality control has been as a detector of production mistakes. If one considers the basic nature of a tire one can visualize a number of possible construction mistakes—missing ply layer, wrong cord size or material in a ply, two cord angles coinciding rather than alternating as they should, plus a number of mistakes possible in the bead area. All of these mistakes can and do happen. Typical factory QC normally catches these mistakes on a sampling basis, but usually only after thousands of questionable tires have been made. Because tires are built in many locations in a plant and funnel together for molding (where the serial number is applied in batches) a mistake at one building station is mixed with normal tires from other building stations. The overall result is typically something like 5% of a suspected batch of tires are really incorrect, but the inability to tell good from bad may cause the scrapage of 100% of the tires—possibly more than $100,000 worth of tires.

Past research with the TDM has shown that the TDM can spot many of these errors and can be used to sort good tires from the bad. The current problem is that human pattern recognition by operators of varying experience can not do this 100% reliably with a 100% confidence factor. Figures 13-15 show schematically some of the type of characteristics we have seen for these anomalies and how they differ from the reflected signals from normal tires. Our currently experienced 70% to 90% reliability should improve with more operator experience at the plants and perhaps some more sophisticated signal processing. Considering the cost of production threatened by these errors we feel that a substantial research effort in this area would be warranted by the tire manufacturers.

Finally, a note about separations. The TDM can spot separations either by scope recognition (Figures 16 and 17) or by the automatic circuitry in the TDM which extinguishes

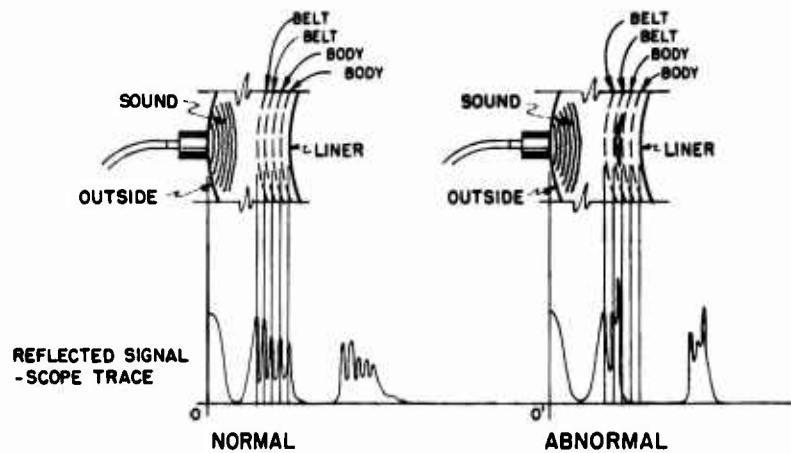1. Results reported by Jim Weir, Tire Consultant, Los Angeles.

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FIGURE 12
COMPARISON OF NORMAL TIRE ULTRASONIC SIGNATURE
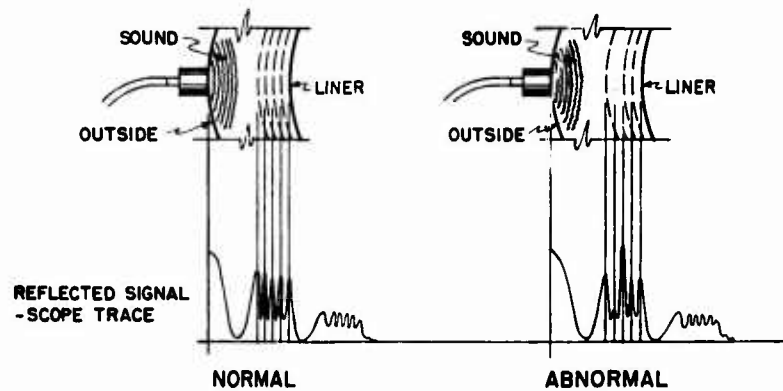WITH INCORRECT TIRE – RADIAL PLY SEPARATION

FIGURE 13
COMPARISON OF NORMAL TIRE ULTRASONIC SIGNATURE
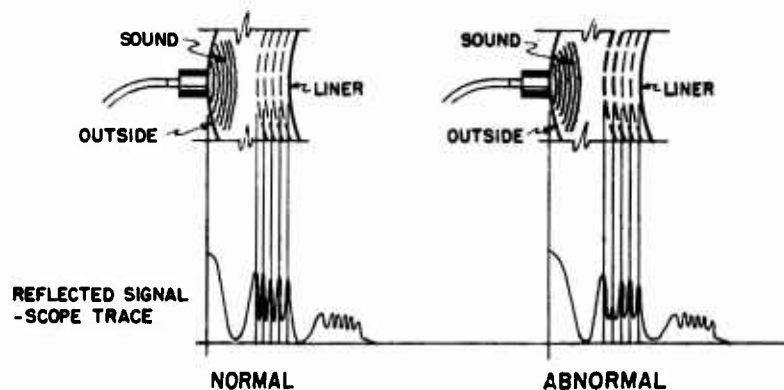WITH INCORRECT TIRE – MISSING PLY CORDS – 2ND PLY

FIGURE 14
COMPARISON OF NORMAL TIRE ULTRASONIC SIGNATURE
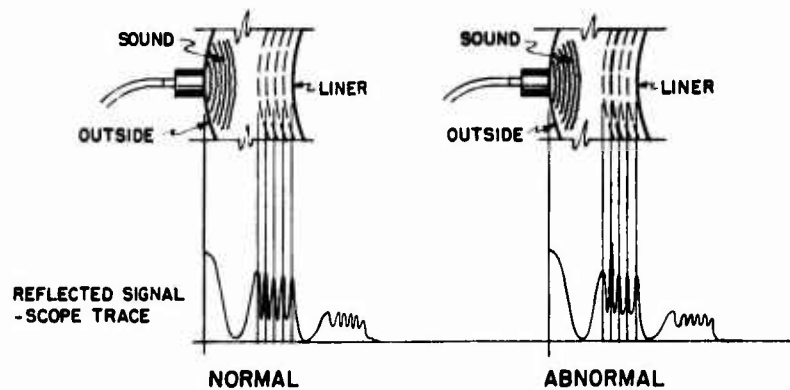WITH INCORRECT TIRE – FIRST 2 PLIES WITH SAME PLY ANGLE

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FIGURE 15
COMPARISON OF NORMAL TIRE ULTRASONIC SIGNATURE
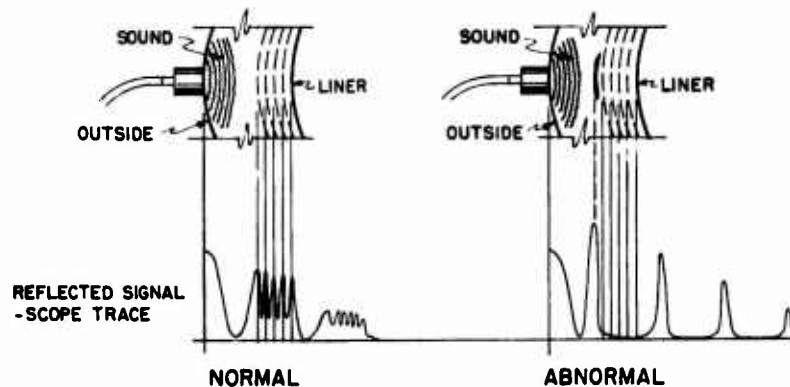WITH INCORRECT TIRE – LARGE CORD – 2ND PLY

FIGURE 16
COMPARISON OF NORMAL TIRE ULTRASONIC SIGNATURE
WITH INCORRECT TIRE – SEPARATION (UNDERTREAD TO TREAD BOND)
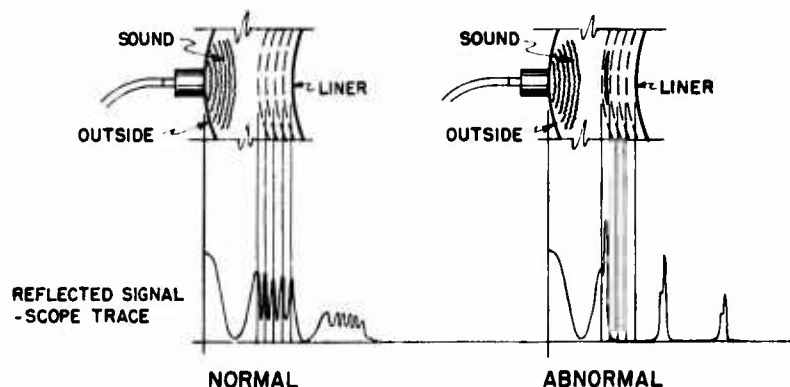
FIGURE 17
COMPARISON OF NORMAL TIRE ULTRASONIC SIGNATURE
WITH INCORRECT TIRE – SEPARATION BETWEEN FIRST & SECOND PLIES

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the digital display and activates a red light. ("Red-light" tires trip this light also without these tires having macroscopic separations. A little experience tells the operator how to distinguish between the two.) But it is too time consuming to search a casing by hand for separations and is not cost-effective. Using the TDM for casing fatigue measurement or QC on suspected areas or tires seems the most cost-effective.

GARD hopes that the tire industry (OEM and Retreaders) will continue to experiment with the TDM. It has an excellent potential to make a substantial improvement in reduction of road service tire failures — especially at a time when a great many radically different tire constructions are being tried, higher pressures are being used, and while at the same time a great effort is being made to reduce tire weight. Real-time NDT techniques that have the potential of being applied economically to 100% of a production run should be carefully explored. It is rather a paradox that retreaded tires can be 100% inspected by electronic NDT techniques at some facilities and yet most new tires are not. The pressure from the government on behalf of its own consuming organizations and the public seems to indicate more work will be done in this area.

QUESTIONS & ANSWERS

Q: With the present TDM, what's the maximum size it can work with and what does it cost?

A: The present cost of the TM is $5,850 and about $400 more to attach the scope. The question of tire thickness is somewhat a nebulous one. We have gone through about 12 to 14 plys for nylon truck tire. You can do thicker tires than that. We've looked at aircraft tires and we've looked at off-the-road tires. Our basic feeling is that for most tire construction the failures tend to occur in the outer plys and it's not very important to look at what goes in down in the lower plys. I know there are certain types of aircraft construction where the tires fold back on themselves and get a lot of failures on the inside of the tire but for most tire constructions, failure does seem to occur in the outer plys so the thickness of the tire isn't very relevant. What you want to do is look at the outer plys and guess what's going on. They're the load carrying plys in normal tire construction.

Q: Do you feel now that you know what transducer and instrument electro-characteristics, frequency, pulse voltages are optimum?

A: I could not say that we've arrived at the optimum one, but we've arrived at one that we find works very well. The transducers that we have are specially made for us after quite a bit of trial and error type of work and do seem to work better than the normal, off-the-shelf transducers. These one megahertz transducers are specially built to work well with rubber tires. Beyond that, I'd have to refer to our ultrasonics expert, Irv Kraska, to tell you more than that.

Q: I was very impressed. But can you inspect for belt placement problems on radial tires, because it's very, very difficult with radial tires.

A: Well, with the TDM held by hand, I'm not certain if you'd know that you had a belt misalignment. You should be able to if you're talking about the runout and this type of thing, lateral runout, you might if you monitored at a fixture and move the tire underneath it to tell whether you had that. With radial tires I might have a tendency to do that with eddy current or something else rather than ultrasonics.

Q: You said here, I recall, that there were 4% rejected tires during inspection. Could you explain that figure?

A: That originally was 4% more than the retreader would normally reject beyond what they would reject for normal visual reasons. This would add to their rejection rate by about 4%. Actually, currently it's running less than that, probably only a couple of percent. What they have done during recent times is to use the casings that are graded to their best advantage. If you have a weak casing and you use it on trailers, then you are likely never to have any problems with it. If it's weak then you throw it out. Even many of these tires which originally were scrapped are now being put on piggyback trailers which never see any real abuse (all they have to do is hold air). So the actual rejection rate caused by the TDM is very, very low. It is important to note that they still do the normal visual inspection.

Q: Have you tried using different frequencies?

A: Yes, with the higher frequency you don't get as much penetration into the tire, with a lower frequency you tend to lose some of the sensitivity. We picked 1MHz to give us the maximum sensitivity and also an optimum penetration into the tire.

**PNEUTEST: A radioactive tracer method for the evaluation of aircraft type quality before retreading.
Method – Apparatus and performances.**

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ABSTRACT

The principle of this method was already presented at the Second Symposium on N D T of tyres (Atlanta – Ga – october 1974).

Since then a prototype of a industrial machine has been designed and manufactured.

With this machine systematic series of test on various tyres of different sizes, different retreading ranks, and in use in different Air Transport Companies has been carried on.

The paper presents a short review of the method, the characteristics of the equipment and results of the test program with emphasis on the statistical analysis of these results in correlation with the life-time of the tyres.

I – INTRODUCTION

Tire failures are still a nuisance in airline operations. Such failures may cause delays, cancellations, structural repairs and in some instances even flight safety may be impaired to various degrees.

That is the reason why many efforts are currently made in order to develop valuable non destructive methods of tire quality evaluation.

One well established method is the airneedle test. Air is injected under pressure into the cords of the carcass by means of a needle prior to retreading. The injected air diffuses along the carcass plies building up an internal pressure. Areas of ply separations from the rubber are shown as local bulges which can be detected by the operator visually and/or by feeling with his hands. These defects occur mainly in the areas shown in Fig. 1. This method is simple to be performed but it has low sensitivity and depends greatly on the operator himself.

The radioactive tracer method [1] (PNEUTEST), which was already presented when the experiments started at the Second Symposium on NDT of tires [2] is a development of this method.

In place of the regular shop air, the injected medium is a mixture of nitrogen and a radioactive gas, xenon 133.

A prototype of an industrial NDT equipment based on this method has been designed and manufactured. With this equipment systematic tests are carried on with the cooperation of AIR-FRANCE, KLEBER and with the financial support of the French Civil Aviation Board (DGAC).

Before describing the equipments and the results, we shall give a brief description of the principle of the method.
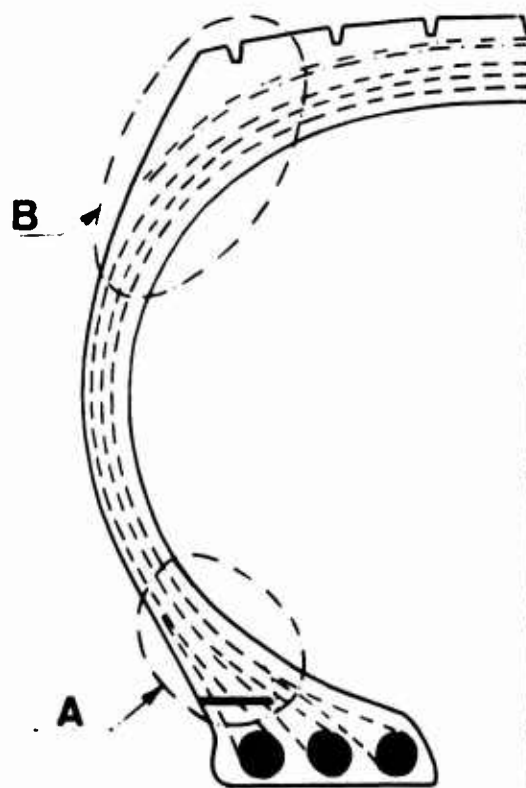

FIGURE 1
TYPICAL SHAPE OF A TUBELESS AIRCRAFT TIRE
(A & B are the areas of maximum fatigue)

II – PRINCIPLE OF THE PNEUTEST METHOD.

II – 1 Injection.

One uses a mixture of nitrogen and xenon 133 (which emits soft γ rays (81 keV) and has a half life of 5.27 days) at a constant pressure of 8 bars (125 PSI).

This radioactive gas is injected with two needles in the vent holes area of the tires (Fig. 2). The injection time varies between 3 to 10 minutes depending on the size and the wear of the tire to be controlled.

II – 2 – Increase of count-rates on points diametrically opposite to the injection points, during the injection.

During the injection one records the count rates of two probes (scintillation probes) which are applied to the tire on points diametrically opposite to the injection points.

As the gas diffuses along the cords of the carcass plies, the count rates increase. This gives a measurement of the diffusion rate of the gas inside the structure of the tire. For new tires this rate is equal to zero and one can observe actually no significant increase of the count rates.

Higher will be the global fatigue of the tire, greater will be the diffusion rate, i. e. the increase of the count-rates.

It seems to us that this method which is rather simple to be operated will be able to detect fatigue of tires at an early stage before any occuring of local defects like blisters.

II – 3 – Scanning of the count rate around the tires.

After the injection and the first control done during it, the needles are disconnected from the tire.

With four probes pressed against the tire, set in a fixed position, in the four areas of maximum fatigue (shoulders
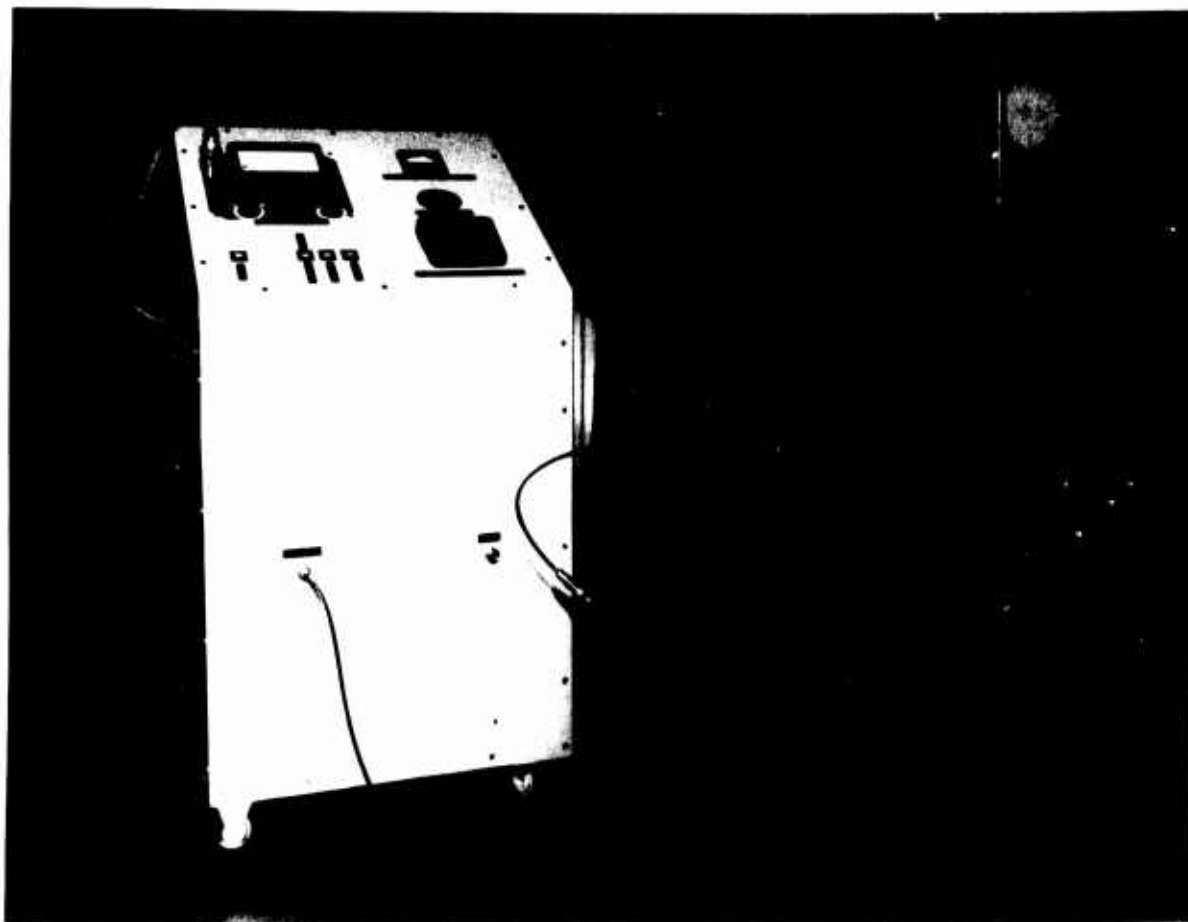

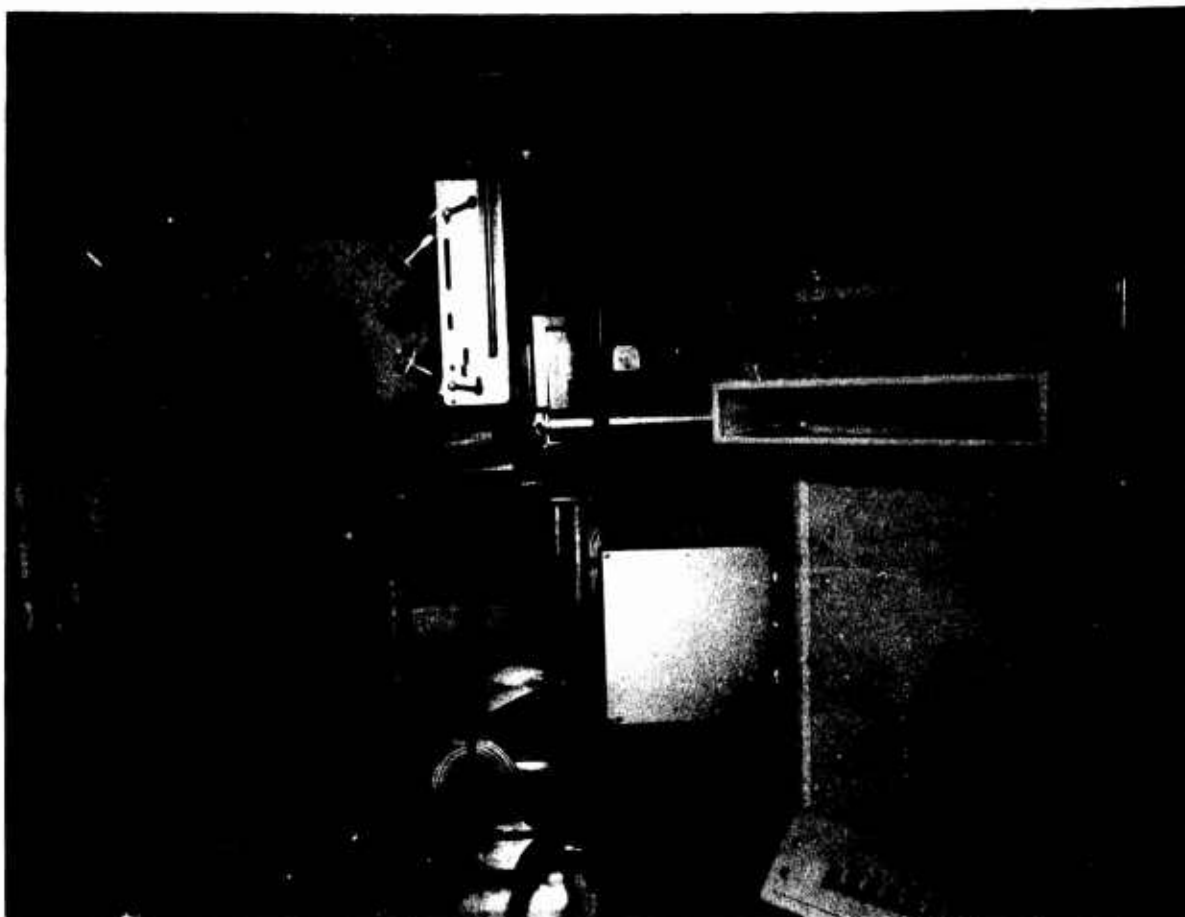
FIGURE 2
INJECTION DEVICE
(the tire shown is a 52 x 20.5)

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FIGURE 3
EXPLORATION MACHINE – STAND-BY POSITION
(the tire shown is a 52 x 20.5)

and beads areas), one makes a scanning of the distributed activity, by rotating the tire around its axis.

So in polar coordinates the activity is maximum just at the injection point, and normally minimum a $180°$ from it.

Using this mode of graphical display of the results, one observes that for a tire which is little used and which presents no local defect the repartition curve of the activity looks like curve I (Fig. 5). The ratio between the count-rate at $180°$ from the injection point (R_{MIN}) and the one over the injection point (R_{MAX}) could represent the global wear of the tire.

So $T_G = \dfrac{R_{MIN}}{R_{MAX}} = 0$ for a new tire

and

$T_G = \dfrac{R_{MIN}}{R_{MAX}}$ has a tendency to approach 1 for a tire "completely" worn

Thus the curve II is a characteristic of a tire more worn than the tire of curve I.

The curve III is a curve of a tire which has the same global porosity (or fatigue) index T_G as the one of the curve II, but it presents 2 local defects.

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III – CHARACTERISTICS OF THE PROTOTYPE EQUIPMENT

III – 1 – Injection device.

It is an electro-pneumatical device (Fig. 2). It needs a regular industrial nitrogen bottle. The pressure is set to about 8 bars (125 PSI). One uses xenon 133 scaled ampules. The mean tracer consumption is less than 0.5 mCi per tire.

For a daily maximum control frequency of 100 tires (in 2 x 8 h), this requires 50 mCi.

The time of injection varies between 3 and 10 mn and can be preset. All the valves are electrically driven and backwards locked. The activity per volume of mixture is continuously measured with an ionization chamber and galvanometric display.

One uses two scintillation probes equipped with thin NaI (Tl) crystals of 1½" diameter, two integrators and a 2 channel linear recorder.

III – 2 – Exploration devices.

The prototype machine is designed to control automatically tires of various sizes (32 x 11.5 – 15 and 35 x 9.00 – 17 up to 52 x 20.5 – 23 in fact 15 to 23 inches rim ledge diameters).

It is an electro-pneumatic device which requires pressured air (6 bars or 90 PSI).

The tire is rolled on the platform (A). Six different sizes of tires can be preset. Then the rails (B) clench the tire. The platform climbs up to set the axis of the tire up to the level of the shaft (C). This one moves forward in the center of the tires. The jaws (D) expand. (Fig. 3).

The rails set the tire free. The four probes are pressed against the sidewalls of the tire. Then the shaft rotates (one revolution in about 5 mn). The four scans are recorded. (Fig. 4).

Then all the mechanical sequences are reversely done. The complete sequence takes about 7 mn.

IV – EXPERIMENTS BEING CARRIED ON.

On various tires of nose wheels or main wheels of various civil transport aircrafts, experiments have been carried on with this equipment for about one year.

The main goals of this work are:

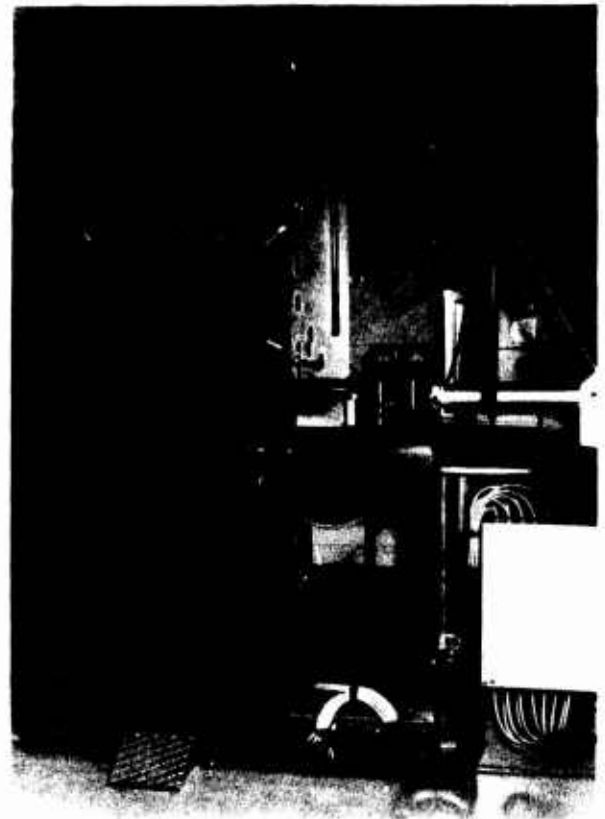(1) determine the various parameters to be taken in account and optimize them,

FIGURE 4
EXPLORATION MACHINE, DURING THE SCAN
(the tire shown is a 52 x 20.5)

(2) make correlation between the rate of diffusion of the tracer gas during the injection and the fatigue of the tire, than means with the number of takings off and touches down. The Figure 6 shows an example of correlation between such values. The tires are 49 x 17/30 PR – 225 MPH from the same manufacturer used on Boeing B 747 SP main wheels of the same company (R02).

(3) make correlation between this rate of diffusion and the excentration of the scans T_G. The figure 7 shows an example of correlation between such values. The tires are 46 x 16/24 PR-210 MPH from the same manufacturer used on Airbus B 2 main wheels of the same company (R00 and R02).

(4) make correlation between eventual local defects shown by the scans and destructive tests in order to be able to predict the type of defect to be detected.

For this reason a lot of 46 x 16/30 PR used on BOEING 747 main gears of the same company were identified and are currently being put in service. Before each retreading all the tires have been controlled in the same manner.
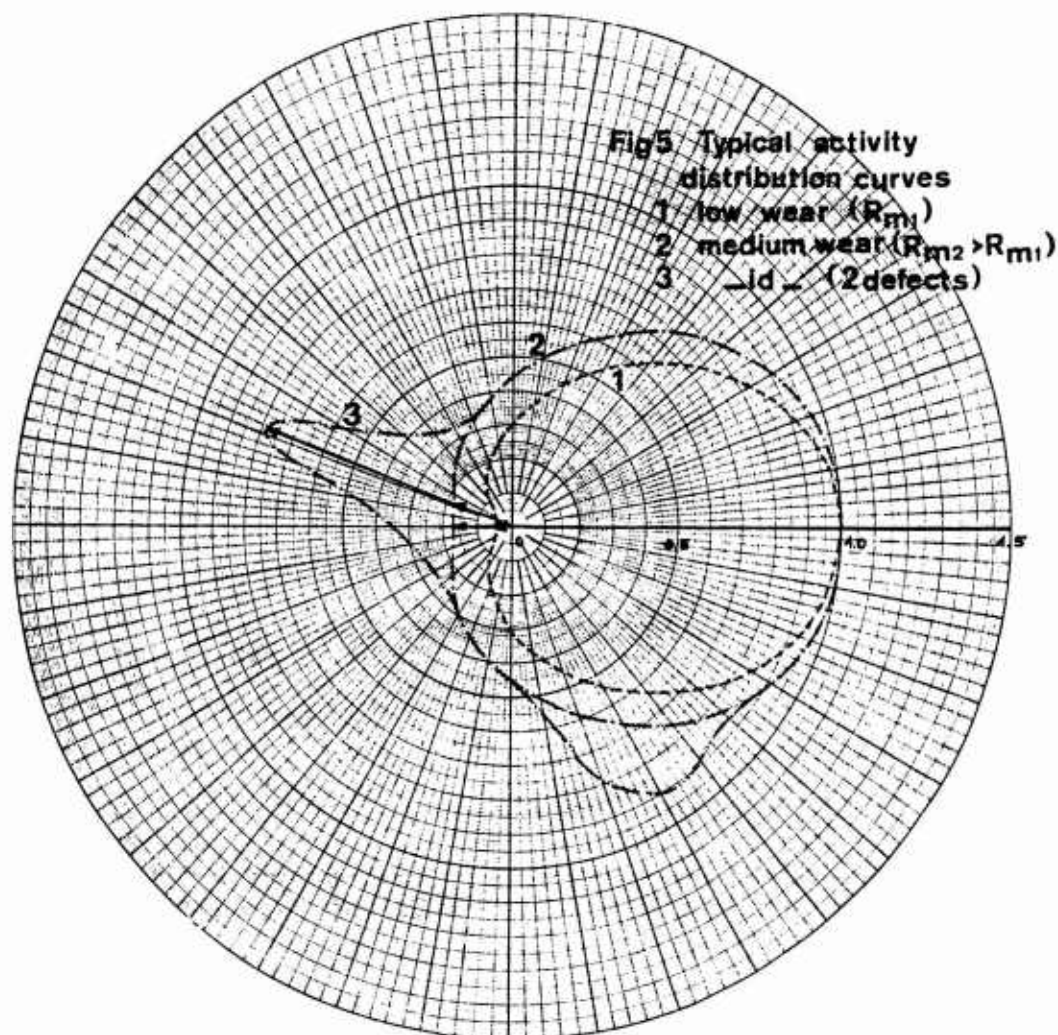
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Fig5 Typical activity
distribution curves
1 low wear (R_{m_1})
2 medium wear ($R_{m_2} > R_{m_1}$)
3 ―Id― (2 defects)

FIGURE 5

All the data are stored on magnetic files in order to check and to study their evolution in connection with the lives of the tire. At each retreading a certain fraction of the lot will be cut to get destructive examination information.

This will be done till all the tires of this population will be withdrawn from duty.

Moreover another series of tires (same manufacturer — same size) have currently been subjected to endurance tests. There are controlled after 200 – 400 – 600 . . . . km rolling tests in the same manner, in order to get quantative equivalence to the data obtained on tires used in airline service.
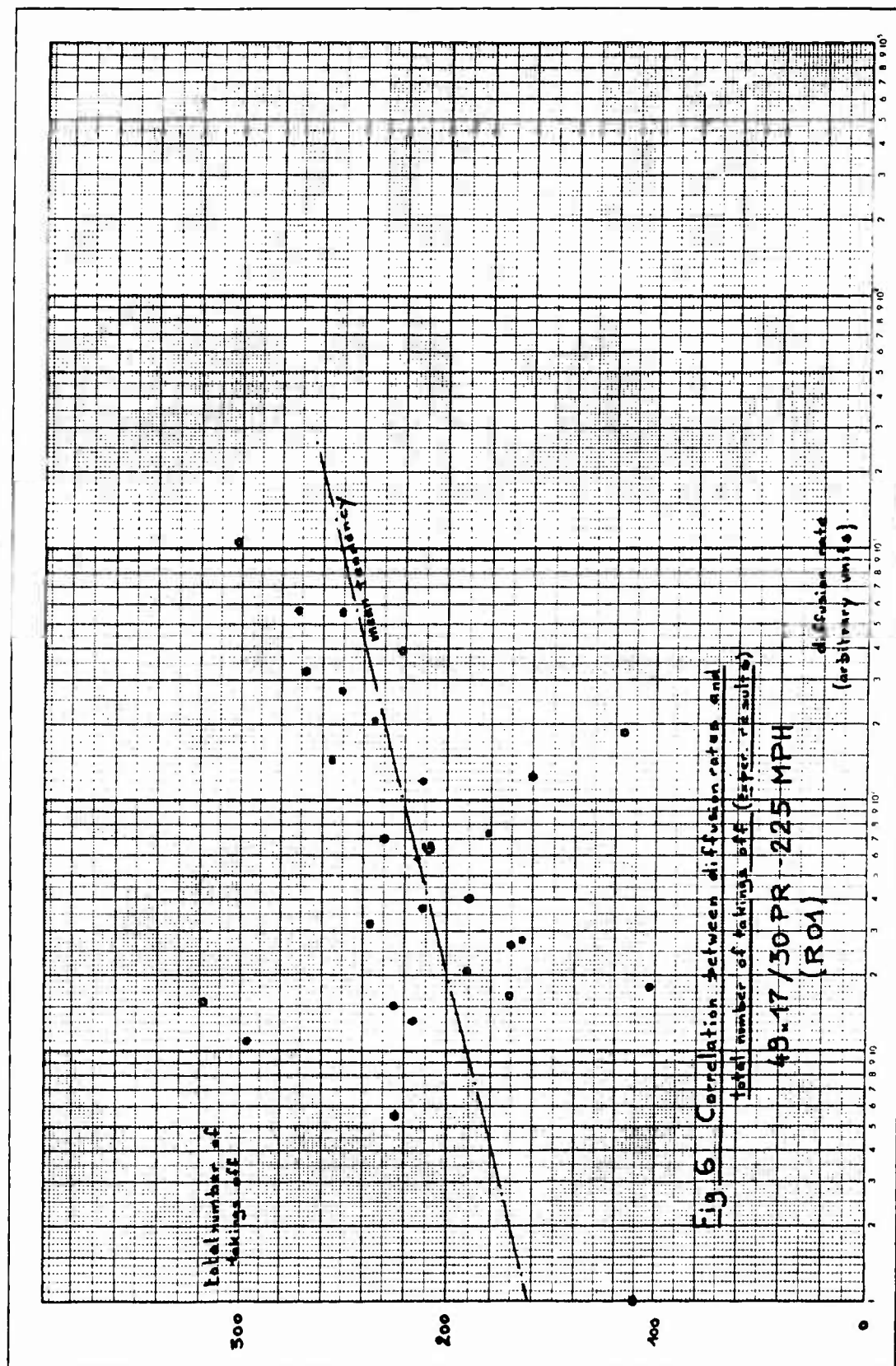
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Fig. 6 Correlation between diffusion rates and total number of takings off (Exper. results)

49×17/30 PR -22.5 MPH (RO1)

FIGURE 6

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Fig. 7 Correlation between diffusion rates and concentrations of the scans (Tc) - Experimental values
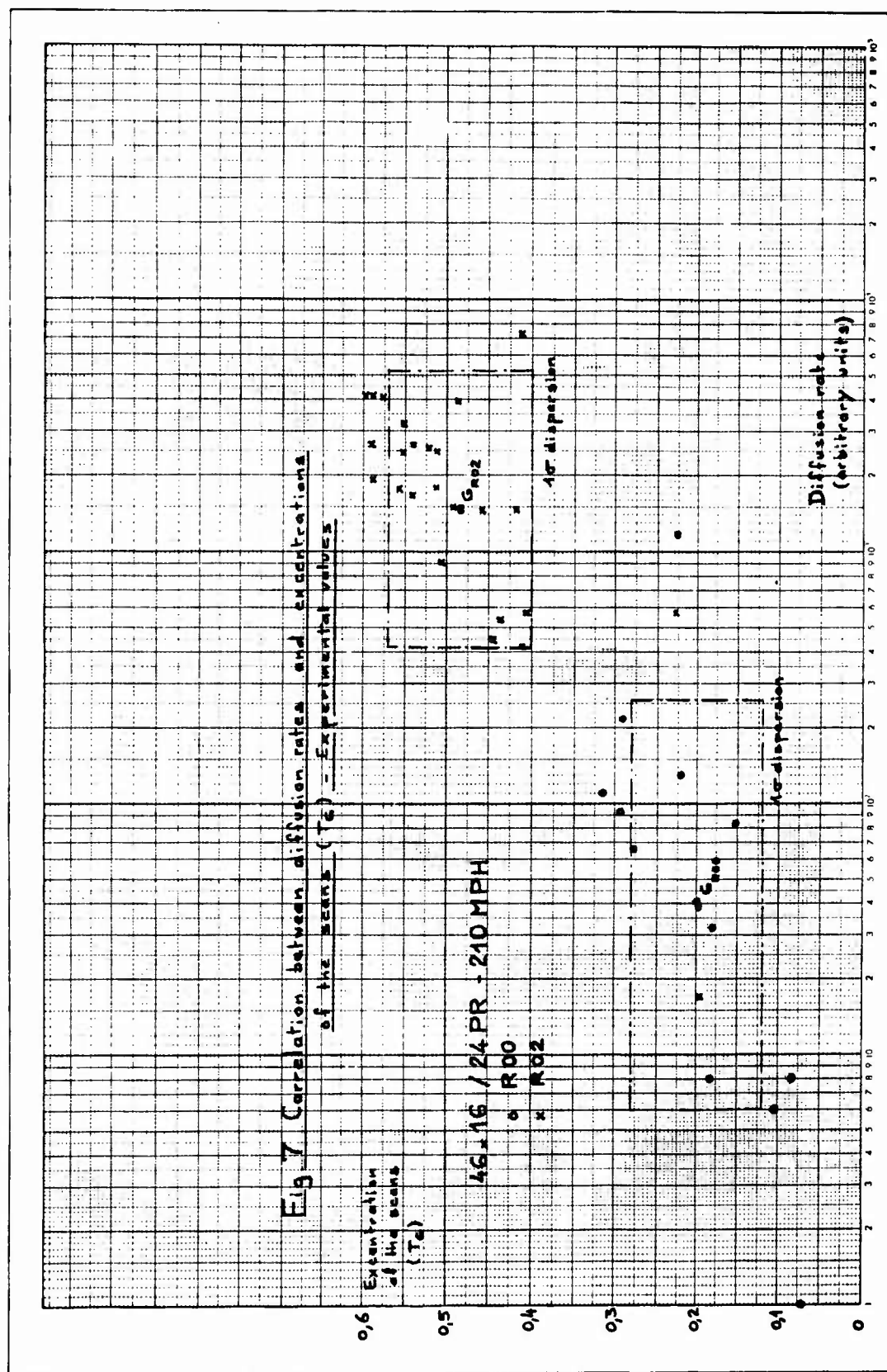
46 × 16 / 24 PR - 210 MPH

R00
R02

FIGURE 7

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V – CONCLUSIONS

The experimental machine has now been in operation for about one year. All the procedure and safety and regulation problems have been carefully solved.

We think that within one year the systematic tests on airline service tires will give us qualitative and quantitative results that will ensure us about the true capability of this method and the associated equipment to help airline companies, tire manufacturers and retreaders to increase the cost/safety balance of aircraft tires exploitation.

We wish to thank the friendly assistance of our colleagues from AIR-FRANCE and KLEBER during all this week and especially M. LAFANECHERE from KLEBER.

Our thanks also go to Mr. Paul E. J. VOGEL for his invitation to this Symposium and for his help to introduce this paper.

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     French Patent n° 2 256 047
     U. S. Patent   n° 3 997 783

[2] BOUTAINE J.L. – ROLL G.
     A radioactive tracer method for NDT of aircraft tires
     2nd Symp. on NDT of tires – ATLANTA – Ga – october 1974

A SECOND GENERATION HOLOGRAPHIC TIRE TESTING UNIT

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Description of the HRT 56

1. Based on many years of experience, not only of holographic tire testing but in many other industrial applications of holography, we have developed a tire testing unit which incorporates the most modern technologies in this field.

The advantages of holographic test methods are already very well known and during the course of this meeting the capabilities of holographic tire testing have already been discussed. Therefore, this paper concentrates on the description of a particular unit with which practical holographic techniques may be applied.

The HRT 56 holographic tire testing unit is exceptional because it incorporates the following special features:

1. The testing process is completely automatic and uses an instant photo-thermoplastic film which is manufactured by the firm of Kalle-Hoechst. Further, the test results are instantly available. The old fashioned methods using silver halide film materials are not only messy and complicated, but also a delay time of test results of up to one hour is involved.

2. Our specially developed optical arrangements makes possible the use of a single hologram per tire. Old fashioned methods using four holograms per tire cost not only time but also money.

3. Bead inspection, so important for truck and aircraft tires, can also be carried out on our specially constructed unit.

The unit is, of course, designed for the severest production environmental conditions and is fully isolated from ambient influences such as dust, vibration etc.

Our holographic tire testing unit is, as a result of the incorporation of the most modern technology and a test capacity of 1000 tires per day, the best test unit of its kind available today.

The holo tire testing unit HRT 56 is suitable for non-destructive testing of tires of all types up to an outside diameter of 56". Individual faults and structural characteristics can be inspected. The unit is the result of many years of development and it is based on the principle of holographic interferometry. The robust construction of the HRT 56 allows a high degree of sensitivity even under noisy operating conditions. Therefore, the unit is suitable for installation on the production floor as well as in the laboratory.

Many tire investigations have shown that holographic tire testing is capable of delivering clear information with respect to:

- tire construction
- quality control
- tire life expectancy.

This guarantees a broad applications field covering virtually the whole tire production spectrum.

2. Principle

The principle of holographic tire testing is based on the fact that faults in the tire produce minute alterations of the surface contour of the inner face when the ambient pressure is slightly changed. Pressure reductions of a few hundredths of an atmosphere lead to contour changes of something less than one thousandth of a millimetre. These minute contour changes can be registered using the holographic technique. Fig. 1 shows the schematic arrangement of the HRT 56 tire testing unit.
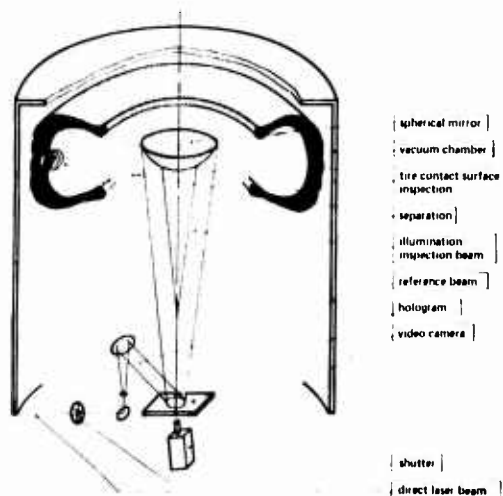

spherical mirror

vacuum chamber

tire contact surface inspection

separation

illumination inspection beam

reference beam

hologram

video camera

shutter

direct laser beam

FIGURE 1
Schematic arrangement of the
HRT 56 tire testing unit.

The holo tire testing method employs a laser to illuminate the inside of the tire. The light reflected from the tire surface goes directly to a photo-sensitive material, without passing through any lenses. By superimposing the laser light returning from the tire with a direct laser beam on the photo-sensitive material (reference beam), the light wave pattern is recorded directly onto the photo-sensitive material. The photo-sensitive material on which the wave pattern is recorded is described as a hologram. Using a particular optical set-up, it is not necessary to divide the tire into portions and make a separate hologram for each portion. A single hologram contains the complete tire information. With the holo tire testing method, the photo-sensitive material is exposed twice. The first exposure is made under normal pressure conditions and the second is made after applying a slight vacuum. The hologram is made on a photo-thermoplastic material which obviates the use of chemicals for development and reduces the whole process to a few seconds. After the short processing time, the wave patterns which have been stored in the hologram are reconstructed by illuminating the hologram with the so-called reference beam. Looking through the hologram (see fig. 2) one can see an interference fringe pattern on the inside of the tire. This pattern shows the contour changes on the inside of the tire to an accuracy of approximately one half of one thousandth of millimetre. The image is viewed at a TV-monitor.
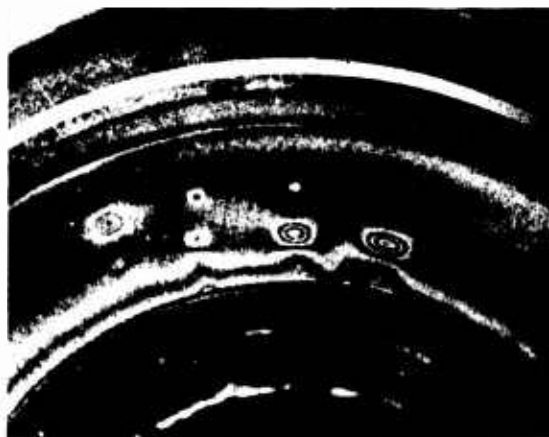

FIGURE 2
Monitor image of a specially prepared tire

The holographic testing method has first been made practical with the introduction of the HRT 56. The use of holography in a production environment was impractical because a wet processing was required with old fashioned photographic materials. This barred the use of holography in production and the first generation

test units were used only in the development field for over ten years. The wet processing was not able to be automated. The holo tire testing unit HRT 56, with its use of a new photo-thermoplastic material has broken through this barrier.

Many new developments in the HRT 56 make it the most advanced unit of its kind at the present time. Some of its particular advantages are the following:

1. extremely short cycle time,
2. completely automatic operation,
3. instant test results,
4. one single hologram for the complete tire,
5. bead inspection without optical adjustment.

3. Image diagnosis

The test results are presented in the form of a TV image. This form of presentation has the advantage of rapid location and quantitative analysis of tire faults. Subjective errors are eliminated. This diagnosis of the monitor image can be applied to virtually all fields of tire manufacture. One of the most important data is concerned with the life expectancy of the tire. The life expectancy, and therewith also the quality of the tire, is influenced considerably by individual faults and by structural weakness in the tire carcass. Both of these effects can be inspected on the TV-monitor.

The tire constructor can establish the tendency to such weaknesses during the construction and testing phase, using the holographic diagnosis technique. Faults can also occur during production due to human error. Faulty material or faulty storage of the tire can lead to a premature fatigue of the tire structure. Holographic testing allows the detection and correction of such faults.

In the field of tire retreading, the life expectance is of major importance. Using holographic testing techniques, faults which have occurred in the past life of the tire may be determined and then decided whether the tire should be retread. Therefore, without any sacrifice of safety factor, a much more economical usage of tire carcasses can be achieved. Other safety factors, such as a larger minimum profile depth, can be taken into account witthout financial burden on the tire user.

The monitor image contains all the necessary information for diagnosis. Individual faults are seen as ring patterns (see fig. 2 and 3) with an elliptical form. The geometrical dimensions of the separation are determined with the help of a mask. Frequently, there are cases of several closely grouped individual faults. These faults, which are typical for belt edge or shoulder area, indicate an extremely dangerous situation as when such individual faults flow together, they drastically shorten the life expectancy of the tire. The monitor image presents
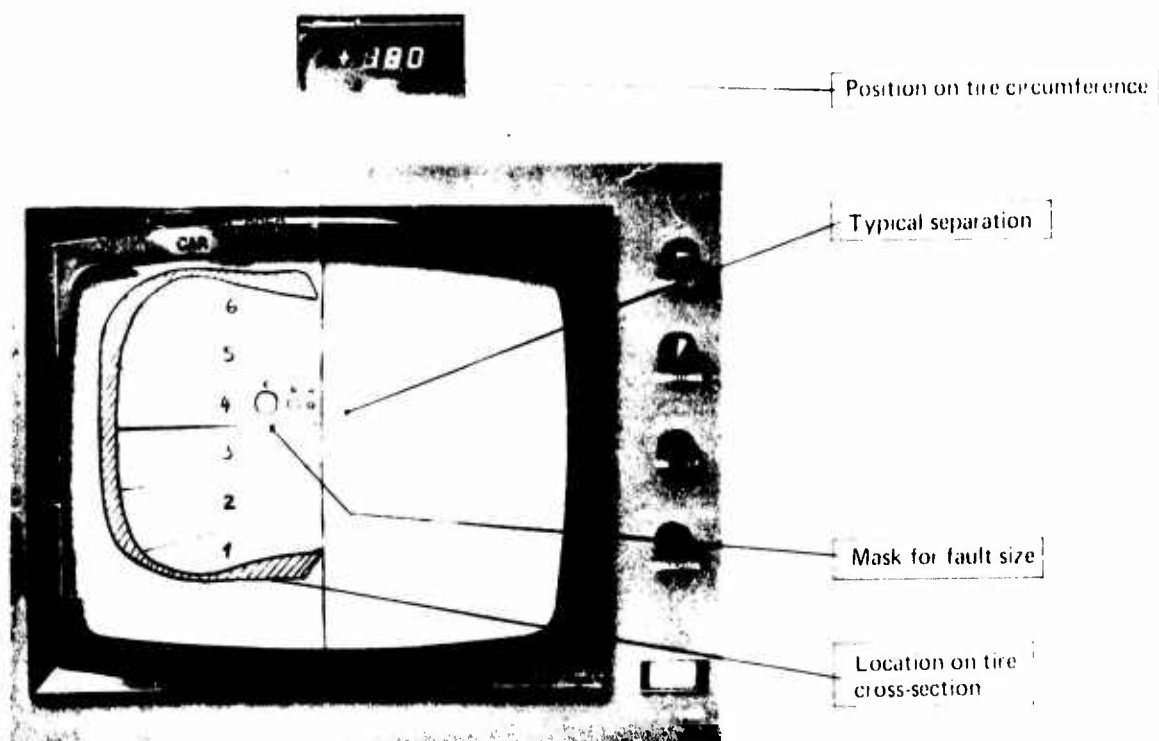
FIGURE 3
Establishing the size and location of a tire fault

FIGURE 4
Chain separations in crown centre

FIGURE 5
Background fringes provide information
about carcass structures.

the possibility to ascertain the likelihood of a flowing together of several closely grouped individual faults. With the use of the mask, the location of the fault can be exactly determined on the tire cross-section (e.g. shoulder area). The depth of the fault can be determined by the number of rings, checked against a master tire. The fault position on the tire meridian is indicated on a digital counter. The carcass structure condition can be inspected by means of the background fringe patterns which run tire circumferentially. The uniformity is indicated by the more, or less central position of the rings. The density and structure of the fringes give an indication of the porosity or degree of fatigue of the tire.

The information which is read out on the TV monitor is transferred to a printed form – an example of which is shown in fig. 6.

The coordination of all the parameters obtained from the image diagnosis allows the assessment of the condition, and therewith also the life expectancy, of a tire. These parameters are:

— fault size (circumferential)
— location of individual faults on meridian (e.g. crown, shoulder, bead)
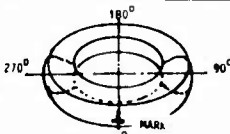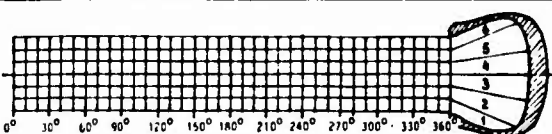— several closely grouped separations
— condition of carcass

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FIGURE 6
Example of Holo tire test printed form

The influence of these parameters on the life expectancy of a particular tire is dependent on the various types of tire construction and must be ascertained for each individual type, whereby specific quality criteria are established in conjunction with the tire manufacturer or retreader.

4. System description

The testing process involves three steps:

- tire manipulation
- automatic test unit functions
- evaluation of the test results on the TV monitor (as described in "Image diagnosis").

The individual function steps can be seen in the following time graph (fig. 8). Time graph I shows the function steps with a one operation, typical for development and limited series applications. Time graph II is for a two man operation in a production environment. With an approx. 80% efficiency in a three shift operation, a figure of 1000 tires per day/tested can be achieved.

4.1 Tire manipulation

Tire manipulation means: on and off-loading of the test unit. For heavy truck and aircraft tires a crane is used. The tire is then placed in a pan, which is apart from the test unit, and is rolled into the unit on a railed platform (shown in fig. 9). The tire is not on a rim. A certain length of time, dependant upon the type of tire under test, is required for the tire to "settle". For car tires, a settling time or relaxing time of approximately five minutes is sufficient, where aircraft tires only require as little as one minute as a result of their more stable structural characteristics. The influence

of the relaxing time on the actual testing time can be obviated in a simple way by having several tire stations. The relaxing stations, which are also used as the loading stations, are constructed on the "building block" principle and can, therefore, be tailored exactly to requirements. A number of different steps are required (depending upon tire type and test-cycle time) when testing tires. If, for instance, a tire life history is being compiled, the serial number and exact fault positioning is most important. This is generally necessary in development applications and retreading quality control. Tires with very dark surface may be sprayed with talcum powder to improve their reflectance. Depending upon tire type and the required tire test area, the tire may be spread open with metal spreading posts. The spreading, however, does lead to a certain lengthening of the relaxing time, and is therefore to be done some time prior to the actual test period.
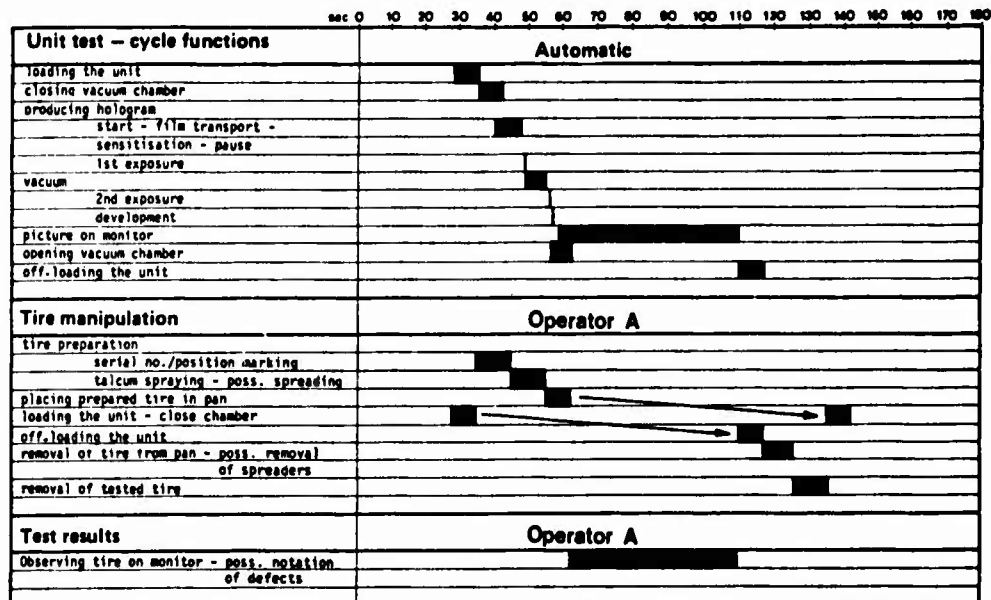
4.2 Test unit

After the tire pan, with the tire, is rolled into the test unit (see fig. 9) the actual testing process begins with the closing of the vacuum chamber bell. (Details may be seen in the time graphs). A vacuum of 0 to 250 mbar can be achieved in the vacuum chamber, and is regulated by a manometer. A so-called double exposure hologram, is made of the tire. The hologram is made on a photo thermoplastic film material which bears the name "PT Instant Film".

The PT instant film was developed by the firm of Kalle-Hoechst AG and Rottenkolber Holo-System has an exclusive licence on this film. The processing is non-chemical and takes only a few seconds. High sensitivity (5 erg/cm^2) high resolution (1000 lines/mm) and a high diffraction efficiency (max. 30% assure good

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FIGURE 8
Time graphs

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SPINDLE

GUIDE RAIL

MIRROR HOLDER

CROWN

INSPECTION

BEAD INSPECTION

VACUUM BELL

PAN

TROLLEY

BASE WITH LASER,
OPTICAL SYSTEM
+RECORDING
SYSTEM
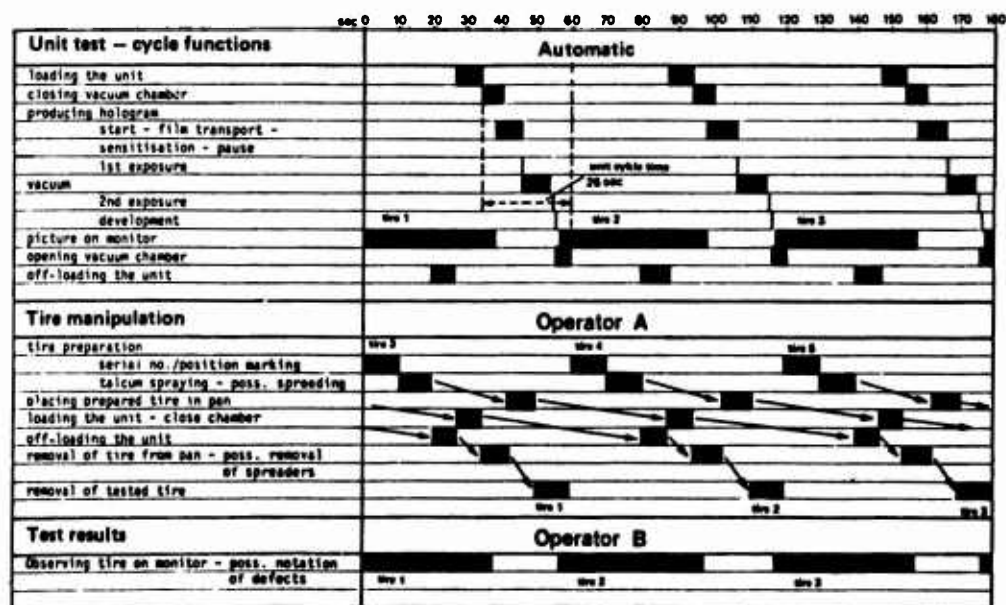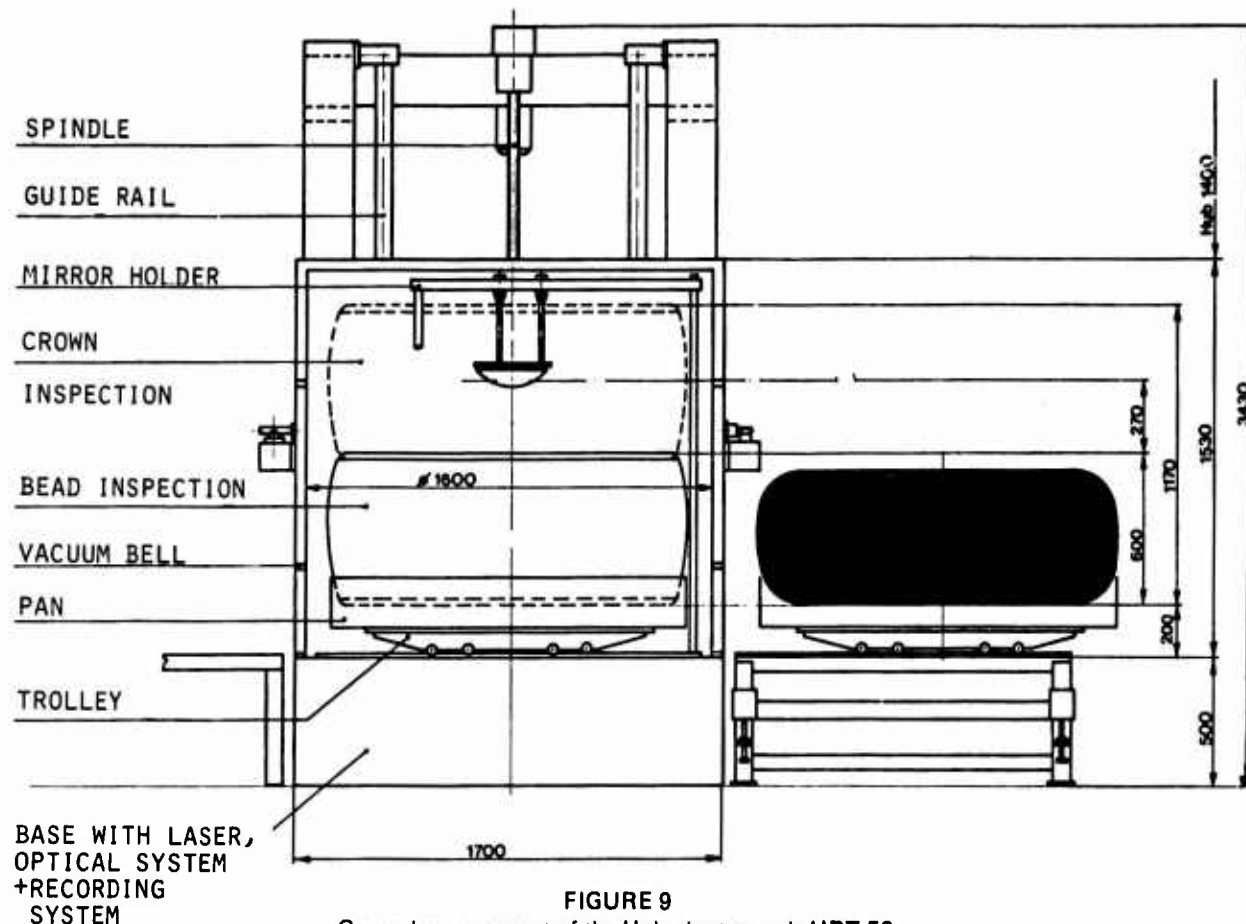
FIGURE 9
General arrangement of the Holo tire test unit HRT 56

quality holograms with a short exposure time and a relatively low light output. The 35 mm film is delivered on spools containing 30 m film length (sufficient for 1000 holograms). The holograms are storable for many years and they can be reconstructed in an external appliance or in the test unit itself. A hologram counter makes the location of particular holograms a simple matter. Therewith, a tire life can be followed through all of its stages and can be compared with previous stages, as required. This is of particular importance when dealing with the study of fault or fatigue problems.

The complete tire circumference can be viewed by a spherical mirror, and therefore, only one single hologram is necessary per tire. The tire image is reconstructed from the double exposure hologram and is inspected by a TV monitor feature. Optical enlargement ensures a high degree of fault resolution. The complete tire is inspected by rotating the TV camera, whereby, the tire position is indicated on a digital counter. Using this counter, an exact location of the fault on the tire circumference can be read. Using the mask, the fault can be located on the cross section of the tire and its geometrical form and size can be established. A subjective faulty diagnosis is largely cancelled out using this method. The test results appear on the TV screen two seconds after exposure.

The holo tire testing unit HRT 56 is equipped with a highly efficient vibration damping system which assures a good quality of holograms even in a production environment. The optics system is sealed off and is thereby kept free of dust. The whole process from loading the unit to viewing the test results on the TV screen is automated. Without the need of readjustment of the optics, all tire sizes can be inspected by means of a simple mechanical adjustment of the tire pan.

5. Testing the bead area

As a second generation system, the HRT 56 makes possible the inspection of the bead area. The inspection of the bead area is of particular importance when dealing with truck and aircraft tires because a large number of the failures which occur in this field of applications, occur in the bead area. For this type of inspection, the only adjustment necessary is the height of the tire pan relative to the spherical mirror. No optical adjustment is required. The fault location, establishing of fault size as well as the cycle time is comparable with that of the crown test cycle. Regardless of tire type, there are three different methods of tire inspection as seen in Figures 10, 11, and 12.

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FIGURE 10

"Bead-crown-bead". — This method is always possible when the tire may be spread apart. It is only used for car tires of special construction. In this case, the tire may be tested in one single test cycle.
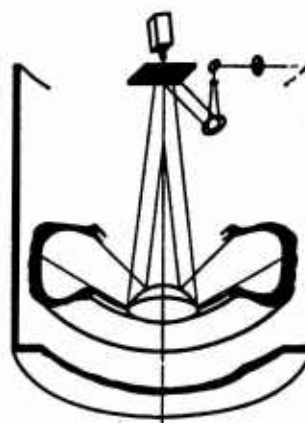

FIGURE 11

"Half-crown-bead". — This method may be used when the tire can be spread apart only a little. Most car and truck tires are under this heading. In this case, two test cycles are necessary.
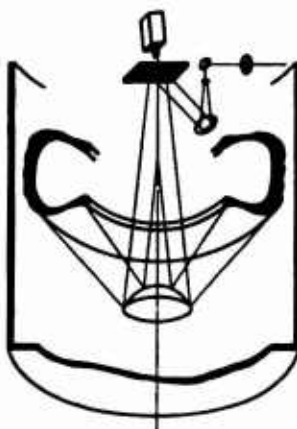

FIGURE 12

"Bead from outside tire". — This method is used when the tire can hardly be spread apart at all, which is in case of most aircraft tires. In this case, three test cycles are necessary.

6. Conclusion

The holo tire testing unit HRT 56 as described here is exceptional in its automatic test cycle. This is made possible by employing the most modern technology. It offers all the prerequisites for "one line" production testing.

Lastly, a look at the cost factors:

Test costs balance of a single tire break down as:

40% unit depreciation
30% running cost
30% personnel cost

The absolute test costs are dependent on the tire type and test capacity factors. As a guide, one may assume approximately one dollar. I feel sure that the relatively modest test costs are justified by the great increase in tire safety which can be achieved using holographic test methods.

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PRODUCTION X-RAY, 1978

T. Neuhaus
Monsanto Company
Akron, Ohio

This paper reviewed recent advances and design changes in production x-ray systems. Modifications have been the result of increased inspection and output demands by the tire industry.

Systems to be discussed were:

1. Computerized Automatic High Production Passenger and Truck Tire Systems.
2. Air Inflated, Automatic Passenger and Light Truck Tire Systems.

SOME NEW TRENDS AND DIRECTIONS IN THE WORLD OF
SPECIFICATIONS AND STANDARDS

R. Chait
Army Materials and Mechanics Research Center
Watertown, Massachusetts

As most of you know, standardization documents that are part of the Defer.se Standardization Program (DSP) are used in the procurement of many DoD items including tires. What I will discuss with you this morning are some of the new trends and directions in the world of specifications and standards as viewed from a DSP perspective. In particular, there have been several studies in recent years that have concerned the DSP that y   ʰould be aware of. I will examine these studies anu ᵖ✶ᵢ.it out some of the recommendations that have been forthcoming. Also, I will describe the DoD followup to these recommendations in terms of new initiatives that have been seen. Lastly, I will comment on just a few of the DSP specifications and standards that deal with tires keeping in mind these initiatives.

To begin, let me show (vu-graph 1) some of the more important studies/hearings that have concerned themselves with our country's standardization efforts. After World War II, Congress became very interested in how the Government was procuring the various items it used during the war effort. To reduce the proliferation of items among the armed services, Congress passed the Cataloguing and Standardization Act in the early 1950s. DoD's answer to this legislation was the DSP which provided for control of item proliferation by a) preventing the preparation of duplicative and overlapping descriptions of materiel, b) fostering reuse of existing technology to satisfy new sys-

tem requirements, c) developing methods for reviewing items in the inventory to reduce or eliminate varieties and sizes, and d) establishing as appropriate, uniform type grades, classes and sizes of items and levels of performance requirements which define physical properties of materiel.

By and large, this program has been successful and has been used as a model for foreign countries to emulate. There are some 46,000 documents in the DSP. These are listed in the Department of Defense Index of Specifications and Standards or what is commonly referred to as the DODISS. To review, each military specification is uniform in its format and contains different sections devoted to the scope of the specification, what other standardization documents are applicable, important requirements, quality assurance provisions to insure requirements are met, delivery aspects and miscellaneous notes. To complete the review, let us examine the first page of a typical document (vu-graph 2). This specification is MIL-A-12650C(MR), Armor Steel Plate, Wrought, Homogeneous; Combat-Vehicle Type (¼ to 6 inches, INCL.), as is shown in the top right-hand corner. "MR" is the abbreviation for the installation charged with the preparation of the document. In this case, it is the Army Materials and Mechanics Research Center (AMMRC). "A" is the first letter in the first word in the title. In the bottom right corner is the identification FSC 9515. As we will see in a moment, all documents that are a part of the

STUDIES/HEARINGS

VU-GRAPH 1

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MILITARY SPECIFICATION

ARMOR, STEEL PLATE, WROUGHT, HONOGENEOUS;
COMBAT-VEHICLE TYPE (1/4 to 6 INCHES, INCL.)

This specification is approved for use by the Army Materials
and Mechanics Research Center, Department of the Army, and
is available for use by all Departments and Agencies of the
Department of Defense.

1. SCOPE

1.1 Scope. This specification covers wrought-steel combat-vehicle
type of homogeneous armor plate in thicknesses from 1/4 to 6 inches in-
clusive (see 6.1 and 6.4).

1.2 Classification. Wrought armor shall be of the following classes as
specified.

1.2.1 Class 1. Wrought armor plate which is heat treated to develop
maximum resistance to penetration.

1.2.2 Class 2. Wrought armor plate which is heat treated to develop
maximum resistance to shock.

2. APPLICABLE DOCUMENTS

2.1 The following documents, of the issue in effect on date of invi-
tation for bids or request for proposal, form a part of this specification
to the extent specified herein.

STANDARDS

FEDERAL
    Fed. Test Method Std. No. 151 – Metals; Test Methods
MILITARY
    MIL-STD-129 – Marking for Shipment and Storage

(Copies of specifications, standards, drawings, and publications re-
quired by suppliers in connection with specific procurement functions
should be obtained from the procuring activity or as directed by the
contracting officer.)

/FSC 9515/

Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be
of use in improving this document should be addressed to: Army Materials and Mechanics Research
Center, Watertown, MA 02172 by using the self-addressed Standardization Document Improvement
Proposal (DD Form 1426) appearing at the end of this document or by letter.

VU-GRAPH 2

DSP are identified with a particular class or area as detailed in the Defense Standardization Program Direction, the SD-1. For example, our standardization responsibilities at AMMRC are varied and cover the classes shown on the next (vu-graph 3).

I would like to return to vu-graph 1 that lists the studies and hearings that have concerned themselves with standardization activities. In 1971, Congressman Hollifield chaired an important House committee which recommended that the responsibility for policy and coordination be assigned to a central point-of-authority which within DoD now rests with the Director, Defense Research and Engineering. In addition, it was stated that this coordination should integrate both development and logistics. For this purpose, the Defense Materials Specifications and Standards Board was established.

AMMRC
STANDARDIZATION MANAGEMENT RESPONSIBILITY

FSC	TITLE
FORG	METAL FORGINGS
MECA	METAL CASTINGS
MFFP	METAL FINISHES & FINISHING PROCESSES & PROCEDURES
MISC	MISCELLANEOUS
NDTI	NONDESTRUCTIVE TESTING & INSPECTION
THJM	THERMAL JOINING OF METALS
3439	MISC. WELDING, SOLDERING & BRAZING SUPPLIES & ACCESSORIES
471C	PIPE AND TUBE
5330	PACKING & GASKET MATERIALS
5345	DISCS & STONES, ABRASIVE
5350	ABRASIVE MATERIALS
6850	MISC. CHEMICAL SPECIALTIES
8010	PAINTS, DOPES & VARNISHES
8030	PRESERVATIVE & SEALING COMPOUNDS
8040	ADHESIVES
8470	ARMOR
91GP	FUELS, LUBRICANTS, OILS & WAXES
9130	LIQUID PROPELLANTS & FUELS (PETRO BASE)
9140	FUEL OILS
9150	OILS & GREASES (CUTTING, LUBRICATING & HYDRAULIC)
9320	RUBBER FABRICATED MATERIALS
9330	PLASTIC FABRICATED MATERIALS
9340	GLASS FABRICATED MATERIALS
9390	MISC. FABRICATED NONMETALLIC MATERIALS
95GP	METAL BARS, SHEETS & SHAPES
9505	WIRE, NONELEC., IRON & STEEL
9510	BARS & RODS, IRON & STEEL
9515	PLATE, SHEET & STRIP, IRON & STEEL
9520	STRUCTURAL SHAPES, IRON & STEEL
9525	WIRE, NONELEC., NONFERROUS
9530	BARS & RODS, NONFERROUS
9535	PLATE, SHEET & STRIP, NONFERROUS
9540	STRUCTURAL SHAPES, NONFERROUS
9545	PLATE, SHEET, STRIP, FOIL & WIRE, PRECIOUS METAL
9630	ADDITIVE METAL MATERIALS AND MASTER ALLOYS
9640	IRON & STEEL PRIMARY & SEMI-FINISHED PRODUCTS
9650	NONFERROUS REFINERY AND INTERMEDIATE FORMS
9660	PRECIOUS METALS PRIMARY FORMS

ASSIGNEE RESPONSIBILITY:

MECA	(J. GALLIVAN)
MFFP	(E. CLEGG)
NDTI	(J. QUIGLEY)
THJM	(H. KLEIN)
8010	(E. CLEGG)
8030	(E. CLEGG)
9640	(J. GALLIVAN)

VU-GRAPH 3

That brings us to 1977 when the Defense Science Board examined the DoD standardization activities and issued a report entitled "Report of the Task Force on Specifications and Standards" dated April 1977. Some of the major findings are shown in vu-graph 4. The major thrusts are to improve the climate of application, upgrade existing body of documents and to provide and maintain high level management attention.

Also in 1977, the National Materials Advisory Board (NMAB) examined that part of the DSP which dealt with materials and materials processing. The result was a report (NMAB Report No. 330) which detailed the following recommendations (vu-graph 5): a) exploit cost-effectiveness potential of standardization, b) increase DoD emphasis on specifications and standards, c) take advantage of voluntary standards system, d) work toward a unified system of specifications and standards, and e) use specifications and standards as a mechanism to cope with shortages, substitution and conservation.

REPORT ON TASK FORCE ON SPECIFICATIONS AND STANDARDS

SHEA REPORT, April 1977

SOME MAJOR FINDINGS:

- SPECIFICATIONS AND STANDARDS ESSENTIAL TO TECHNICAL PROCUREMENT

- PRESENT BODY OF MILITARY SPECIFICATIONS AND STANDARDS IS ADEQUATE TO THE NEEDS OF DoD

- SPECIFICATIONS AND STANDARDS CONTAIN CORPORATE HISTORY OF LESSONS LEARNED

- MAJOR PAYOFF FOR IMPROVEMENT IN SPECIFICATIONS AND STANDARDS WILL COME INITIALLY IN THEIR METHOD OF APPLICATION FOLLOWED BY LONGER RANGE IMPROVEMENTS IN CONTENT.

VU-GRAPH 4

MATERIALS AND PROCESS SPECIFICATIONS AND STANDARDS

NMAB REPORT 1977

SOME MAJOR FINDINGS:

- EXPLOIT COST-EFFECTIVENESS POTENTIAL OF STANDARDIZATION

- INCREASE DoD EMPHASIS ON SPECIFICATIONS AND STANDARDS

- TAKE ADVANTAGE OF VOLUNTARY STANDARDS SYSTEM

- WORK TOWARD A UNIFIED SYSTEM OF SPECIFICATIONS AND STANDARDS

- USE SPECIFICATIONS AND STANDARDS AS A MECHANISM TO COPE WITH SHORTAGES SUBSTITUTION AND CONSERVATION.

VU-GRAPH 5

DoD DIRECTIVE 4120.21, April 1977

TITLE: "SPECIFICATIONS AND STANDARDS APPLICATION"

SCOPE: REQUIRES ALL DoD COMPONENTS TO ESTABLISH SPECIFIC AND CONTINUING
MANAGEMENT CONTROLS OVER THE UTILIZATION OF SPECIFICATIONS, STANDARDS
AND RELATED TECHNICAL DATA IN THE ACQUISITION PROCESS TO ASSURE THEY
ARE PROPERLY APPLIED AND TAILORED TO REFLECT THE MINIMAL ESSENTIAL
REQUIREMENTS FOR THAT PARTICULAR SYSTEM.

VU-GRAPH 6

Both the Defense Science Board study, which examined
the entire DSP, and the NMAB, which examined only those
documents pertaining to materials and materials processes,
have led to important new initiatives. I would like to discuss
some of them now.

First. DoD Directive 4120.21 entitled "Specifications and
Standards Application" issued during 1977 (vu-graph 6).
The thrust here is not to treat the entire specification as
sacred but to only use that portion of the document ap-
plicable, thereby reducing the cost of the item. This con-
cept is known as "tailoring."

The second initiative is also in the form of an official DoD
policy (DoD Instruction 4120.20, "Development and Use
of Nongovernment Specifications and Standards") which is
detailed in the next vu-graph (vu-graph 7). As you can see,
emphasis is placed on the adoption and use of nongovern-

ment documents as well as on participation in standards
writing body activities such as American Society for Test-
ing and Materials (ASTM). In other words, if there is a
private sector document that is duplicating the military
document, the latter should be cancelled. This is a tall
order but some progress is being made as is shown on
the next vu-graph (vu-graph 8). I should mention that the
rate of adoption of private sector documents is not ex-
pected to increase indefinitely at the rate shown, since
there is a finite number of documents that can be adopted.
Therefore, the curve will probably bend over and level off.

The last initiative which I would like to cover this morning
is one given the acronym CCAP standing for Commercial
Commodity Acquisition Program. Additional details are
provided on the next vu-graph (vu-graph 9). This initiative
is still in the pilot stage emphasizing the procurement of
items such as gasoline.

DoD INSTRUCTION 4120.20

December 1976

TITLE: "DEVELOPMENT AND USE OF NONGOVERNMENT SPECIFICATIONS AND STANDARDS"

SCOPE: PLACES GREATER EMPHASIS ON 1) ADOPTION OF NONGOVERNMENT SPECIFICATIONS
AND STANDARDS, 2) USE OF NONGOVERNMENT SPECIFICATIONS AND STANDARDS
IN THE DESIGN AND DEVELOPMENT OF MATERIEL, 3) DoD PARTICIPATION IN THE
DEVELOPMENT AND ADOPTION OF NONGOVERNMENT DOCUMENTS IS PREFERRED
TO THE DEVELOPMENT OF A NEW, REVISED MILITARY OR FEDERAL DOCUMENT,
AND 4) DoD DEPARTMENTS AND AGENCIES ACTIVELY PARTICIPATE IN NONGOVERN-
MENT BODIES ENGAGED IN THE PROMULGATION OF NONGOVERNMENT DOCUMENTS.
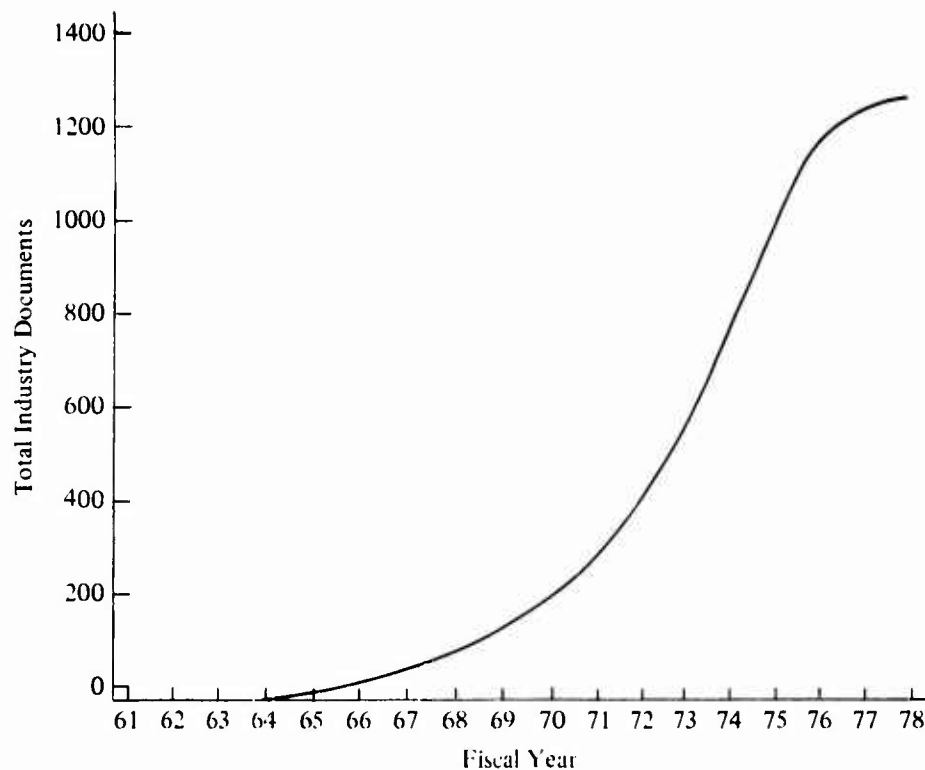
VU-GRAPH 7

Figure 1. NUMBER OF INDUSTRY DOCUMENTS LISTED IN DODISS AS A
FUNCTION OF TIME.

VU-GRAPH 8

OFPP STATEMENT

May 1976

TITLE: "COMMERCIAL PRODUCT ACQUISITION"

SCOPE: THE GOVERNMENT WILL PURCHASE COMMERCIAL, OFF-THE-SHELF
PRODUCTS WHEN SUCH PRODUCTS WILL ADEQUATELY SERVE THE
GOVERNMENT'S REQUIREMENTS, PROVIDED SUCH PRODUCTS HAVE
AN ESTABLISHED COMMERCIAL MARKET ACCEPTABILITY.

ALSO, THE GOVERNMENT WILL UTILIZE COMMERCIAL DISTRIBU-
TION CHANNELS IN SUPPLYING COMMERCIAL PRODUCTS TO ITS
USERS.

VU-GRAPH 9

It should be noted that as part of a continuing effort to reduce cost, DoD has identified through the Defense Science Board report categories that are candidates for misapplication and misinterpretation. These cost driver areas are shown in the next vu-graph (vu-graph 10). From this, a list of FSC areas or classes that bear on these cost driver areas have been compiled and are shown in this vu-graph (vu-graph 11).

GENERAL COST DRIVER SPECIFICATIONS

- GENERAL DESIGN REQUIREMENT SPECIFICATIONS
- ENVIRONMENTAL REQUIREMENTS AND TEST METHODS
- RELIABILITY AND MAINTAINABILITY
- QUALITY CONTROL
- HUMAN FACTORS AND SAFETY
- DOCUMENTATION
- CONFIGURATION CONTROL
- INTEGRATED LOGISTIC SUPPORT
- PACKING, PACKAGING, PRESERVATION, TRANSPORT

VU-GRAPH 10

STANDARDIZATION COST DRIVER AREA ASSIGNMENTS AND PROGRAM PLANNING

AREA	LEAD SERVICE	ASSIGNEE
RELIABILITY	DMSSO	DMSSO (SD)
ELECTROMAGNETIC COMPATABILITY	NAVY	NAVELEX (EC)
CONFIGURATION MANAGEMENT	NAVY	NAVMAT (NM)
DOCUMENTATION	(UNASSIGNED)	
QUALITY CONTROL/ASSURANCE	ARMY	ARRADCOM (AR)
NONDESTRUCTIVE TESTING & INSPECTION	ARMY	AMMRC (MR)
PACKING, PACKAGING, PRESERVATION & TRANSPORTABILITY	ARMY	TOBYHANNA (SM)
HUMAN FACTORS & SAFETY	ARMY	MIRADCOM (MI)
ENVIRONMENTAL REQUIREMENTS & RELATED TEST METHODS	AIR FORCE	AFSC/ASD (11)
GENERAL DESIGN REQUIREMENTS	AIR FORCE	AFSC/ASD (11)
THERMAL JOINING OF METALS	ARMY	AMMRC (MR)
SOLDERING	ARMY	MIRADCOM (MI)

VU-GRAPH 11

In this regard, one FSC class of importance, and one for which AMMRC has responsibility, is Nondestructive Testing and Inspection (NDTI). I would like to spend a few minutes describing the approach that we have taken in light of the above initiatives. The first step is to put together a time-phased program plan whose objective is detailed in the next vu-graph (vu-graph 12). One of the main ingredients here is to list for subsequent evaluation all documents that comprise the NDTI area. This has been done as shown in the next group of vu-graphs (vu-graph 13 - vu-graph 17).

DoD STANDARDIZATION AREA PROGRAM PLAN – NDTI

THE PROGRAM PLAN PROVIDES A TIME-PHASED DELINEATION OF TASKS REQUIRED TO OVERCOME OBSOLESCENCE, OVERLAP, AND VOIDS IN THE BODY OF MILITARY STANDARDIZATION DOCUMENTS DEALING WITH NON-DESTRUCTIVE TESTING AND INSPECTION (NDTI).

THE THRUST OF THIS DOCUMENT IS TO DEFINE, SCHEDULE, PLAN AND CONTROL THE NECESSARY STANDARDIZATION ACTIVITIES WITHIN THE DoD, AND TO REFLECT CONCURRENCE AND COMMITMENT BY THE SERVICES TO THE ACCOMPLISHMENT OF SPECIFIC ASSIGNMENTS WITHIN SCHEDULED MILESTONES.

VU-GRAPH 12

NDT STANDARDIZATION DOCUMENTS

INTRODUCTION

On the following pages are listed the more common standardization documents dealing with NDT.

The listing is broken down into several groups relating to specific NDT areas. The areas identified are:

General

Radiography

Ultrasonics

Penetrant

Electromagnetic (Eddy Current)

Magnetic Particle

Leak Testing

The listing shown is as current and thorough as practicable (compiled as of March 1978). The reader is cautioned to first check the latest issue of the DODISS (or other applicable indexes of technical society publications) to ascertain availability and currency of any document referenced. A list of NDT standardization handbooks and pertinent quality assurancy pamphlets is included.

VU-GRAPH 13

GENERAL

MIL-STD-271	Nondestructive Testing Requirements for Metals. (Radiography, Magnetic Particle, liquid Penetrant, Leak Testing, Ultrasonics).
MIL-STD-798	Nondestructive Testing, Welding Quality Control, Material Control & Identification & Hi-Shock Test Requirements for Piping System Components for Naval Shipboard Use. (Radiography, Magnetic Particle, Penetrant).
MIL-I-6870	Inspection Requirements, Nondestructive for Aircraft Materials and Parts (Magnetic Particle, Penetrant, Radiographic, Ultrasonic, Eddy Current).
ASNT-TC-1A	Recommended Practice Nondestructive Testing Personnel Qualification & Certification. (Supplement A, Radiographic Testing; Supplement B, Magnetic Particle; Supplement C, Ultrasonic Testing; Supplement D, Liquid Penetrant; and Supplement E, Eddy Current).
AWS - A2.2-58	Nondestructive Testing Symbols (Replaces MIL-STD-231).
Air Force TO-00-25-224	Welding High Pressure and Cryogenic Systems (Section 4 – Nondestructive Inspection by Ultrasonic and Eddy Current Methods).
ASME	ASME Boiler and Pressure Vessel Code. Section I, Section III, Section VIII, Section IX, Division 2, and Section IV.
MIL-STD-410	Qualification of Inspection Personnel
ASTM	Index to ASTM Standards
ASTM	Book of Standards, Part 11
ASTM E543	Determining the Qualification of Nondestructive Testing Agencies

VU-GRAPH 14

PENETRANTS

(See General Section)

MIL-I-6866	Inspection; Penetrant, Method of.
MIL-I-25135	Inspection Materials, Penetrant (ASC).
MIL-F-38762	Fluorescent Penetrant Inspection Units.
Air Force T.O. 42c-I-10	Inspection of Materials; Fluorescent and Dye Penetrant Methods.
MSFC-STD-366	NASA Standard: Penetrant Inspection Method.
ASTM A462	Method for Liquid Penetrant Inspection of Steel Forgings.
ASTM B165	Standard Methods for Liquid Penetrant Inspection.
ASTM B270	Terms Relating to Liquid Penetrant Inspection.
AMS 2645	Fluorescent Penetrant Inspection.
AMS 2646	Contrast Dye Penetrant Inspection.
AMS 3155	Oil, Fluorescent Penetrant, Water Soluble.
AMS 3156	Oil, Fluorescent Penetrant, Water Soluble.
AMS 3157	Oil, Fluorescent Penetrant, High Fluorescence, Solvent Soluble.
AMS 3158	Solution, Fluorescent Penetrant, Water Base.

VU-GRAPH 15

ULTRASONIC

(See General Section)

MIL-STD-770	Ultrasonic Inspection of Lead.
MIL-I-8950	Inspection, Ultrasonic, Wrought Metals, Process for.
MIL-U-81055	Ultrasonic Inspection, Immersion, of Wrought Metal, General Specification for (Torpedo MK 46 MCD O).
NAVSHIPS 0900-006-3010	Ultrasonic Inspection, Procedure & Acceptance Standards for Hull Structure, Production Repair Welds.
AISI	Industry Practices for Ultrasonic Nondestructive Testing of Steel Tubular Products.
AISI	Ultrasonic Inspection of Steel Products.
Al. Assoc.	Ultrasonic Quality Limits for Aluminum Mill Products.
Al. Assoc.	Ultrasonic Standards for Plate, Extruxions and Forgings.
AMS 2630	Ultrasonic Inspection.
ASTM A578	Longitudinal Wave Ultrasonic Testing and Inspection of Plain and Clad Steel Plates for Special Applications.
ASTM E113	Ultrasonic Testing by the Resonance Method.
ASTM E114	Ultrasonic Testing by the Reflection Method Using Pulsed Longitudinal Waves Induced by Direct Contact.
ASTM E127	Fabricating and Checking Aluminum Alloy Ultrasonic Standard Reference Blocks.
ASTM E164	Ultrasonic Contact Inspection of Weldments.
ASTM E215	Ultrasonic Inspection of Metal Pipe and Tubing for Longitudinal Discontinuities.

VU-GRAPH 16

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RADIOGRAPHIC

(See General Section)

MIL-STD-139	Radiographic Inspection; Soundness Requirements for Aluminum and Magnesium Castings (For Small Arms Parts).
MIL-STD-437	X-Ray Standard for Rare Aluminum Alloy Electrode Welds.
MIL-STD-453	Inspection, Radiographic.
MIL-STD-746	Radiographic Testing Requirements for Cast Explosives.
MIL-STD-775	X-Ray Standards Welding Electrode Qualification and Quality Conformance Test Welds.
MIL-STD-779	Reference Radiographs for Steel Fusion Welds; Vol. I 0.030", 0.080" and 3/16"; Vol. II 3/8", 3/4" and 2.0"; Vol. III 5.0".
MIL-STD-1238	Radiographic Inspection; Soundness Requirements for Steel Castings (For Small Arms Parts).
MIL-STD-1257	Radiographic & Visual Soundness Requirements for Cobalt-Chromium Alloy Liners (For Small Arms Barrels).
Fed. Std. - No. S2	X-Ray Tube Focal Spot, Method of Measurement.
MIL-R-11468	Radiographic Inspection, Soundness Requirements for Arc and Gas Welds in Steel.
MIL-R-11469	Radiographic Inspection, Soundness Requirements for Steel Castings.
MIL-R 11470	Radiographic Inspection, Qualification of Equipment, Operators & Equipment.
NAVSHIPS 0900-003-9000	Radiographic Standards for Production and Repair Welds.
MIL-R-45774	Radiographic Inspection, Soundness Requirements for Fusion Welds in Aluminum & Magnesium Millise Components.
MIL-R-51060	Radioactive Test Sample, Strontium 90 and Yttrium 90, Beta, M6.
MIL-C-6021	Casting; Classification and Inspection of.
MIL-R-81080	Radiographic Inspection, Quality Levels for (Torpedo MK MOD O).

VU-GRAPH 17

Having done this, an analysis is performed where some important questions have to be asked. Do documents need updating? Have advances in NDT been included? Are there pertinent private sector documents? Is there overlap in documents? Is the CCAP program applicable here?

Perhaps a similar approach should be taken with regard to those FSC areas that pertain to tires and which are of interest to those of you in the audience this morning. These FSC areas are 2610 – Tires and Tubes, Pneumatic, Except Aircraft; 2620 – Tires and Tubes, Pneumatic, Aircraft; 2630 – Tires, Solid and Cushion; and 2640 – Tire Rebuilding and Tire and Tube Repair Materials.

From a quick examination of the DODISS, these FSC Classes (vu-graph 18) account for approximately 35 documents (vu-graph 19 - vu-graph 20). Obviously, we don't have time to discuss all of these documents. However, I did pick out three for comment:

MIL-T-12459C, Tire, Pneumatic: For Military Ground Vehicles. Examination reveals the plunger test is utilized as a quality assurance provision (vu-graph 21). Following the plunger test, the tire is then examined and a visual examination is then made for hidden defects. How much better it would be to utilize a true nondestructive test. From what I've heard this morning, some of these NDT type tests appear to be very promising and perhaps are ready for incorporation into standardization type documents.

MIL-STD 698A, Quality Standards for Aircraft Pneumatic Tires and Inner Tubes. With regard to aircraft tires, it is seen (vu-graph 22) that many defects for tire treads are mentioned. However, no reference standard is given for "moisture or air under the surface" as shown in vu-graph 23. How do we evaluate that particular defect?

The next example pertains to MIL-STD-1224, Visual Inspection Guide for Pneumatic Tires (Nonaircraft). Here, many figures (vu-graph 24 - vu-graph 27) are devoted to visually detected defects. However, how many of these are applicable to radial tires?

24GP	TRACTORS							
2410	TRACTORS, FULL TRACK, LOW SPEED	ME		YD	99	CS	CS	5
2420	TRACTORS, WHEELED	ME		YD	99	CS	CS	5
2430	TRACTORS, TRACK LAYING, HIGH SPEED	AT		YD	99		AT	5
							3	
25GP	VEHICULAR EQUIPMENT COMPONENTS							
2510	VEHICULAR CAB, BODY AND FRAME STRUCTURAL CMPTS	AT		YD	99	CS	CS	1
2520	VEHICULAR POWER TRANSMISSION COMPONENTS	AT		YD	99	CS	CS	1
2530	VEHICULAR BRAKE, STRG, AXLE, WHEEL AND TRACK CMPTS	CS	AT	YD	99		CS	1
2540	VEHICULAR FURNITURE AND ACCESSORIES	CS	AT	YD	99		CS	5
2590	MISCELLANEOUS VEHICULAR COMPONENTS	CS	AT	YD	99		CS	5
							5	
26GP	TIRES AND TUBES							
2610	TIRES AND TUBES, PNEUMATIC, EXCEPT AIRCRAFT	AT		YD	99		AT	1
2620	TIRES AND TUBES, PNEUMATIC, AIRCRAFT	99	AV	AS			99	1
2630	TIRES, SOLID AND CUSHION	A7		YD	99		A7	5
2640	TIRE REBUILDING AND TIRE AND TUBE REPAIR MATERIALS	A7		YD	99		AT	5

VU-GRAPH 18

VU-GRAPH 19

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		Description	Spec No.		Date			
L	2620	Tire Pneumatic Rebuilt, Type Iii 12.50-16.12 Pr	MS-22080	99	10 Jun 77		AS	99
L	2620	Tire Pneumatic Retread Type Vii 56 X 16.24 Pr	MS-27812	99	21 Dec 70			99
L	2620	Tire Pneumatic Retread, Type Vii 20 X 4.4 / 12 Pr	MS-27821B	99	12 Nov 73			99
L	2620	Tire Pneumatic Retread, Type Vii 30 X 8.8 / 22 Pr	MS-27819	99	21 Dec 70			99
L	2620	Tire Pneumatic Retread, Type Vii 36 X 11 /22 Pr	MS-27817A	99	01 Apr 78			99
L	2620	Tire Pneumatic Retread, Type Vii 38 X 11 / 14 Pr	MS-27818A	99	01 Apr 78			99
L	2620	Tire Pneumatic Retread, Type Vii 49 X 17/26 Pr.	MS-27811A	99	01 Apr 78			99
L	2620	Tire Pneumatic Retread, Type Vii 56 X 16 / 34 Pr.	MS-27816	99	21 Dec 70			99
L	2620	Tire Pneumatic Retread, Type Vii 56 X 16 % 38 Pr. 250 Mph	MS-27813	99	21 Dec 70			99
L	2620	Tire Pneumatic Retread, Type Vii 56 X 1632 Pr	MS-27814	99	21 Dec 70			99
L	2620	Tire Pneumatic Retread, Type Viii 31 X 11.50 - 16/22 Pr	MS-27820	99	21 Dec 70			99
L	2620	Tire Pneumatic Retread, Type VII 44 X 16, 28 Pr	MS-27815B	99	01 Apr 78			99
	2620	Tire Pneumatic Type Vii 20 X 4.4/12 Pr	MS-22076	99	10 Jun 77		AS	99
	2620	Tire Rebuilt 26 X 6.6/14 Pr.	MS-22078	99	10 Jun 77		AS	99
L	2620	Tire-aircraft 20 X 5.5 Type Vii (Navy) Validated Feb 75.	MS-3374	AS	20 Dec 68		AS	
L	2620	Tire-aircraft, 24 X 5.5 (200 Mph) Fabric Tread Type Vii (Navy) Validated Feb 75.	MS-18060A	AS	17 Dec 67		AS	
L	2620	Tire-aircraft, 26 X 6.6 (200 Mph) Type Vii (Navy) Validated Apr 74.	MS-26564A	AS	15 Jun 67		AS	
L	2620	Tire-aircraft, 40 X 14 (200 Mph) type Vii (Navy) Validated Nov 73	MS-26563A	AS	14 Jul 67		AS	
L	2620	Tire-casing - Aircraft, 24 X 5.5 Type Vii (Navy) Validated Nov 73	MS-26526B	AS	1 Dec 61		AS	
	2620	Tire-pneumatic Rebuilt, Type Vii 20.00 20/26 Pr	MS-27823A	99	28 Sep 77		AS	99
	2620	Tire-pneumatic Type Iii 12.50-16/12 Pr.	MS-22079	99	10 Jun 77		AS	99
L	2620	Tire/casing - Aircraft, 18 X 5.5 Type Vii (Navy) Validated Nov 73	MS-26535A	AS	1 Dec 61		AS	
L	2620	Tire/casing - Aircraft, 20 X 4.4 Type Vii (Navy)	MS-27538B	AS	20 Jun 75		AS	
L	2620	Tire/casing - Aircraft, 22 X 5.5 Type Vii (Navy) Validated Nov 73	MS-26539A	AS	1 Dec 61		AS ·	
L	2620	Tire/casing - Aircraft, 22 X 8.8 Type Vii (Navy) Validated Nov 73	MS-26537A	AS	1 Dec 61		AS	
L	2620	Tire, Aircraft 22 X 6.75-10 135 Knots (Navy).	MS-14161	AS	25 Nov 74		AS	
L	2620	Tire, Aircraft, 26 X 8.75-11 (Navy).	MS-14160	AS	16 Oct 74		AS	
L	2620	Tire, Aircraft, 28 X 9.0 Type Vii (Navy)	MS-90443B	AS	31 Jul 74		AS	
L	2620	Tire, Casing - Aircraft, 24 X 7.7 Type Vii (Navy) Validated Nov 73.	MS-26558A	AS	1 Dec 61		AS	
L *	2620	Tire, Pneumatic - Aircraft, 25 X 6.0 Type Vii (Navy)	MS-26543A	AS	08 Apr 75		AS	
	2620	Tire, Pneumatic New Type Iii 20.00-20.26PR	MS-22081	99	10 Jun 77		AS	99
	2620	Tire, Pneumatic, New Type Vii 26 X 6.6/14 Pr	MS-22077	99	10 Jun 77		AS	99
L	2620	Tire, Pneumatic-helicopter Ground Handling, 3.50-6 Validated Feb 77	MS-87013	AV	29 Jun 64	AV		
Q	2620	Tire, Pneumatic, Aircraft USER-MC REV-IA	MIL-T-5041G (1)	11	04 Mar 77	AV	AS	11
L	2620	Tire, Pneumatic, Aircraft 30X11.50-14.50, Type Viii(Navy) Fabric Reinforced Tread	MS-14171	AS	22 Dec 76		AS	
L	2620	Tire, Pneumatic, Aircraft, Rebuilt, 30 X 11.50-14.50, Type Viii (Navy) Fabric Reinforced Tread	MS-14172B	AS	12 Dec 77		AS	
L	2620	Tire, Pneumatic, Aircraft, Rebuilt, 30 X 8.0-16.00, Type Vii (Navy) Fabric Reinforced Tread	MS-14176	AS	13 Jan 77		AS	
L	2620	Tire, Pneumatic, Aircraft, Rebuilt, 27 X 11.5 - 16, Type Vii	MS-14170A	AS	23 Jan 78		AS	
L	2620	Tire, Pneumatic, Aircraft, 24 X 6.5-14 Fabric Reinforced Tread (200 Knots)	MS-14178	AS	11 Apr 78		AS	
L	2620	Tire, Pneumatic, Aircraft, 26 X 6.6, Type Vii (Navy)	MS-26533D	AS	09 Feb 78		AS	
	2620	Tire, Pneumatic, Aircraft, 34 X 9.9-16.	MS-14162	AS	06 Mar 75	AV	AS	99
L	2620	Tire, Pneumatic, Aircraft, 36 X 11 High Speed, Type Vii (Navy)	MS-90346A	AS	31 Jan 78		AS	
	2620	Tire, Pneumatic, Aircraft, 44X13 High Speed-type Vii	MS-26557A	AS	27 May 75		AS	99
	2620	Tire, Pneumatic, Rebuilt, Aircraft, 34 X 9.9-16.	MS-14167	AS	17 Feb 76	AV	AS	99
L	2620	Tread Tire-aircraft 24X5.5 (200 Mph) Type Vii (Navy) Validated Mar 75.	MS-3381	AS	18 Feb 69		AS	
	2630	Tire, Cushion Permissable Sizes And Loading For Use On Original Material Handling Equipment Validated Nov 70 USER-MC AS OS CS	MS-16966A	SA	28 Jun 65	GL	SA	99
	2630	Tire, Solid Permissible Sizes And Loading for Use On Original Material Handling Equipment Validated Nov 70.	MS-16967A	SA	28 Jun 65		SA	99
	2630	Tire, Solid Rubber, And Wheels, Solid Rubber Tire, (Industrial) Validated Apr 74 USER-MD MC REV-AT	ZZ-T-391D	/ME	11 Dec 70	ME	YD	99
Q	2630	Tire, Solid Rubber, And Wheels, Solid Rubber Tires Validated May 75 USER-ME MC REV-MI.	MIL-T-3100B	AT	22 Apr 63	AT		99
L	2630	Wheel, Solid Rubber Tires, Rebuild Of USER-ME	MIL-W-46759A (1)	AT	10 May 74	AT		
	2640	Adapter, Pneumatic Tire Valve - Liquid	MIL-A-28677	YD	10 Sep 73		YD	99
L	2640	Cement, Thread, Rubber.	MIL-C-42123	AT	18 Feb 70	AT		
	2640	Compound, Lubricating, Inner Tube, Aircraft Tire Validated Dec 70 USER-ME-REV-IS	MIL-C-5024A (1)	99	02 Jun 65		AS	99
L	2640	Lubricant, Mold, Tire, Silicone Base Emulsion Validated Jul 75 REV-EA.	MIL-L-3921A	AT	05 Jan 71	AT		
	2640	Lubricant, Tire And Rim, Demounting, Validated Feb 76 USER-ME MC REV-AV AS	MIL-L-8362C	99	10 Oct 68	AT	YD	99
	2640	Patch, Pneumatic Tire Repair - Semi-cured Nylon Validated Mar 77 USER-MC	MS-52124	AT	22 Sep 72	AT	YD	99
	2640	Patch, Pneumatic Tire Repair, Chemical Cured Nylon And Vulcanizing Fluid Validated Mar 77.	MS-52123	AT	22 Sep 72	AT	YD	99
	2640	Patch, Pneumatic Tire Repair, Uncured Validated Sep 76 USER-MC.	MS-51312	AT	16 Jul 59	AT	YD	99
	2640	Patch, Repair, For Inner Tubes and Tubeless Tire Liners USER CS REV-AR	ZZ-P-112D (1)	/AT	27 Jul 74	AT	YD	99
L	2640	Repair Kit, Puncture, Pneumatic Tire REV-SM ME	MIL-R-45949A	AT	23 May 77	AT		
	2640	Tire, Pneumatic, Retread And Repair Materials.	ZZ-T-416G	/AT	26 Sep 75	AT	YD	99
	2640	Tire, Pneumatic, Retreaded And Repaired REV-MC.	ZZ-T-441D (3)	*AT	15 Feb 77	AT	YD	99
L	2640	Tread Rubber, for Recapping Pneumatic Tires, And Solid Rubber Tires for Industrial And Track Laying Vehicles, Packaging and Packing Of, Validated May 76	MIL-T-13584B	AT	30 Apr 76	AT		
	2640	Tread Rubber, Solid Rubber Tire For Track Laying Vehicles USER-MC.	MIL-T-45301B INT AMD I (AT)	AT	20 Nov 75	AT	YD	99
L	2640	Tread Rubber, Strip Form Stock, For Retreading Tires Validated Nov 74	MIL-T-62118	AT	22 Sep 99	AT		
QL	2640	Valve Care, Pneumatic Tire, Inner Tube and Tubeless, Aircraft REV-CS.	MIL-V-27317 (2)	99	24 Mar 78			99
	2640	Valves And Valve Spuds Caps And Cores, Pneumatic Tire USER-ME AS OS MC CG SH	ZZ-V-25D (2)	*AT	20 Sep 77	AT	YD	99

VU-GRAPH 20

MIL-T-12459C

4.5.2.4.4 <u>Thickness</u>. After the tire has been cut to determine hidden defects (see 4.5.3.2), the thickness of the sidewalls and undertread shall be measured in accordance with method 2011, 2021, or 2121 of Standard FED. TEST METHOD STD. NO. 601.

4.5.3 <u>Breaking energy and hidden defects</u>.

4.5.3.1 <u>Breaking energy plunger test</u>.

4.5.3.1.1 <u>Procedure</u>. After the mounted tire in 4.5.2.4 has been measured as specified in 4.5.2.4.1 through 4.5.2.4.3 inclusive, a cylindrical steel plunger, 1¼ inches in diameter and hemispherical at the working end, shall be forced into the center of the tread portion of the inflated tire at the rate of 2 inches per minute to determine the force and penetration at break. Five measurements of force and penetration at break shall be made at points equally spaced around the circumference of the tire. In the event that the tire fails to break before the plunger is stopped by reaching the rim, the force and penetration shall be taken as this occurs. The energy value to determine conformance to 3.5 and table IV shall be calculated from the average values at break using the following formula:

$$W = \frac{F \times P}{2}$$

Where W = energy at break, inch pounds.

     F = force at break, pounds.

     P = penetration at break, inches.

4.5.3.2 <u>Hidden defects</u>. After the plunger test has been made, the tire shall be subjected to visual inspection to visual inspection for hidden defects. This shall be done by cutting the tire in ten radial sections, with each section being cut, circumferentially, in midcrown and on each side of crown, near breaker edge at point of maximum shoulder thickness; any additional cuts deemed necessary for complete inspection of the tire shall be made. The cut sections shall then be inspected for evidence of separation of tread, ply, cord, or bead.

4.5.4 <u>Tensile strength and elongation</u>. After being checked for hidden defects the tire shall be subjected to tests for tensile strength and ultimate elongation of tread and sidewall, to determine conformance to 3.6 and 3.7 respectively.

4.5.4.1 <u>Preparation of test specimens</u>. Test specimens shall be cut (longitudinally at center of tread or sidewall) with a die No. VII of method 4111 of Standard FED. TEST METHOD STD. NO. 601. On tread specimens, the nonskid portion shall be sliced off with a knife, after which the central portion shall be buffed on each side over a length of 2½ inches until free from friction compound, fabric impressions, or irregularities of surface. In case specimens cut with die No. VII cannot be obtained, specimens may be cut with a die No. IV of method 4111 of the same standard. On sidewall specimens, rubber solvent shall be used, if necessary, to separate rubber and fabric and one or both sides shall be buffed as necessary. For class MR tread test specimens, tread shall be removed from wire.

VU-GRAPH 21

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TABLES

VU-GRAPH 22

TABLE I. – Classification of defects in accordance with Standard MIL-STD-105.

Cate-gories	AQL percent defective	Items	Defects	Paragraph or specification reference
MAJOR:	1	Tire treads:		
101			Moisture or air under surface is unacceptable.	
102			Open tread splice whre immediately below tread splice there is a hollow area in the carcass.	5.2.2.2
103			Porosity in tread ribs is unacceptable.	
104			Cord outline visible in tread grooves (unacceptable except in special-purpose tires which vere qualified with that conditior).	5.3.1
105			Mold flash or rind at tread register: (a) Tires from open or cocked molds with a depression in the carcass. (b) Tires from open or cocked molds where tread flash thickness exceeds:	5.2.2.1
			Tire cross section — Open register	
			8 inches or less — 0.06-inch	
			More than 8 inches and less than 15 — 0.13-inch	
			15 inches and longer — 0.18-inch	
106			Off-register molds (tires from off- or out-of-register molds wehre radial stepoff, at tread rib, between the two halves, exceeds 0.03-inch).	5.2.2.1

VU-GRAPH 23

MIL–STD–1224
15 September 1960

CONTENTS

FIGURES

Figure

VU-GRAPH 24

FIGURES–Continued

Figure

VU-GRAPH 25

FIGURES–Continued

VU-GRAPH 26

FIGURES–Continued

Figure

127. Diagonal wear due to heavy tread splice.
128. Construction features of typical 4-ply passenger car tire.
129. Construction features of typical highway truck tire.

TABLES

Table I.   Classification of Defects.

VU-GRAPH 27

Standardization has brought us a long way in this country, and is responsible in large part for the standard of living we enjoy today. However, the time is ripe to upgrade the standardization effort. I believe that the current directions described in this presentation will do just that and result in long range beneficial effects on the entire DoD standardization effort. However, it will require top management's continuing support to sustain the momentum that has been initiated. Both ingredients are necessary to insure that Gillette's criterion of specification ("What the buyer needs and what the vendor is willing to sell him.") are met.

DISCUSSION OF THE NEED FOR SOME STANDARDIZATION
IN THE FIELD OF NDT OF TIRES

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ABSTRACT

Non Destructive Inspection of tires has become a funda-
mental part of tire development. There are many different
techniques, each employing various basic principles and
methods of inspection and also utilizing numerous types of
equipment. There are equally as many directions and goals
being pursued and answers being obtained.

Is it possible that this is the time for the introduction of a
standard to obtain a common language and set a realistic
goal for the good of consumers, suppliers, manufacturers
and inspectors?

During the initial phase of tire development there have
been found numerous general categories of irregularities
which can conceivably exist in a complex tire of today.
Considering the various components, multiple belts and
plies and the significant locations in a tire, there can exist
an impracticable number of individual inspections which
would be required to detect and identify each potential
irregularity.

With some exceptions, each anomaly has a direct or in-
direct bearing on the overall performance of the tire.
Depending on its degree of severity, it would be difficult
to classify these as to their importance.

To detect a large variety of these conditions, there exist
a multiplicity of industrial Non-Destructive Inspection
(NDI) pieces of equipment. All of these methods of NDI
have been found, from our experience, to have significant
present limitations, along with their attributes. There
simply does not yet exist a single Panacea NDI technique.

Consider the following:

X-ray is a vital and presently irreplaceable technique for
technique for detecting blows, and defining geometric
placements and conditions of beads, belts, plies, and many
components. It is our experience, however, that X-ray
is greatly limited in locating many critical thin line ply
and belt separations as well as other irregularities detected
by other methods.

Experience with ultrasound techniques indicates excellent
potential for various areas of tire inspection. These include,
but are not limited to, the measurement of gauge variation,
location of foreign material and separations.

Due to the wide variations in acoustical impedance between
certain materials, however, there has been considerable dif-
ficulty in detecting specific critical separations and other
irregularities.

There is also a wide variation in potential use and limita-
tions of reflective vs. thru techniques for ultrasonics.

Holography or Holographic Interferometry can be used to
detect separations and locate their position and depth
within acceptable limits. It also can be used to detect gross
non uniformities, under certain conditions, and other
anomalies.

Holography is not without its limitations. In the bead area,
and turn-up region of a tire, holography can be ambiguous,
time consuming and lacking correlation for many tire con-
structions. Holography is limited when utilized to determine
the severity of a non uniformity of a new tire or in cases of
multiple non uniformities.

In essence, most popular NDI techniques have considerable
merit and value and while their coverage may overlap, many
significant anomalies will escape one or the other or all
techniques.

I would like to make a crude analogy between a tire and the
physical make up of a human being. To predict a tire's life
span is akin to expecting a doctor to predict a life span of
a baby at birth. There are obvious tell-tale signs in rare
cases which may be reason for concern. But it would be a
monumental and probably an insurmountable task to
achieve a single test which would guarantee a life expect-
ancy of either. It would be difficult to diagnose a heart
murmur using an encephalogram or a brain tumor using a
stethoscope. Just as there are well established medical tests
to diagnose various diseases, there is also, based on experi-
ence, specific NDI techniques to diagnose some of the
various tire syndromes.

If it were known to a doctor that the new born infant was to be a long distance runner or was to survive in an environment requiring superhuman stamina, as that required of a high performance tire, he may be directed to performing tests with fairly conclusive evidence of survivability. This may also be the case with specific types of tires.

For the sake of discussion, consider the separation. Separation growth during service may or may not correlate with durability. Separations may grow, remain dormant, grow and become dormant, or even diminish in size, for some passenger tires for example, with increased mileage.

A distinct advantage that the tire companies have in evaluating NDI techniques is in the development stage of the tire design. Many experimental passenger and truck tire designs which are thwarted because of poor road and lab wheel test results indicated excellent correlation to various NDI techniques which were used to monitor the tire during its test cycle. Contrary to this, many passenger tires which pass exhaustive road and wheel testing generally indicate poor correlation to NDI techniques when monitored regardless of the anomalies they may develop.

Not all irregularities are detected or identified by the most popular methods of NDI. There are numerous techniques applied when specific problems are suspected.

It would be a mistake and a step backward to propose or single out a unique method of NDI. This would indicate an over reliance on that method and possible subjugation of other valuable methods, thus relaxing an overall vigilance required to produce a quality tire.

We then come to the problem of attempting to establish standards. The mere fact that there are nearly 275 methods of NDI or NDT used to assist in providing some quality assurance for over 700,000 tires manufactured per day, suggests that setting standards may be premature. Yet the mere numbers involved also imply that some type of standard is desirable if we are to obtain continuity and give direction to the NDI equipment manufacturers.

Then I ask, what type of standard would not be premature?

I would propose as a beginning to establish a glossary of terms which would at least result in a common language.

As a second step, I would propose a calibration sample, similar to a stepped block used in X-ray. The stepped block could be improved to incorporate various construction techniques similar to that used in a tire. Programmed flaws of all types could be built into blocks and these blocks could be available to the various NDI equipment manufacturers.

As a third step, I would propose eventually extending this technique to a series of calibration tires of contemporary design. Flaws could then be built into these tires for final evaluation of equipment. The type of calibration tires could include, but not be limited to, passenger, truck, airplane, military and retread tires.

There would be a multitude of problems realized with such a proposal. Obtaining a manufacturer and agreeing on construction, type of flaws, etc. would only be a few; however, I do believe it would be a worthwhile adventure and a beginning.

ULTRASONIC TIRE INSPECTION

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ABSTRACT

For the past several years, TARADCOM has been involved in various ultrasonic, holography and radiography tire inspection evaluation programs. The primary objective of the tire testing program is to eliminate or minimize defective tires, which would fail prematurely, from entering the retread system. Based on cost, safety, hardware required to perform the testing, and other considerations, the best inspection technique to meet the Army's needs is considered to be pulse-echo ultrasonic testing of tires. Therefore, the TARADCOM Product Assurance Directorate's Tire Inspection efforts have been concentrated in this area of NDT of tires. The plans for the current and future TARADCOM Tire Inspection Programs, which have been initiated to solve specific problems and satisfy particular user hardware requirements, will be discussed.

INTRODUCTION

Tire degradation is defined as a defective rubber to cord bond or the unraveling of the cords themselves. Detection of degraded tires is impossible by visual inspection of a retread candidate tire. The result of retreading a tire with degraded cord structure is premature failure of the retread tire. Early failures relate to lost investments. In most cases the cost of shipping the tires to the retreading facility is not recoverable. The same is true for the expenses

for material and labor expended on tires that fail during retreading or are rejected after retreading. Only a portion of the expenses of retreading a tire are recovered for tires that fail in the field before they reach their useful life expectancy. However, these premature failures pose not only a dollar loss to the Army, but also create a potential safety hazard for the personnel operating the vehicle on which the tires fail.

In response to these problems, hardware requirement definitions for two different types of tire testing equipment have been generated (Figure 1). An inexpensive, easy to use tire tester is needed for posts, camps, and stations to inspect tires before they are shipped to the retreading facilities. This tester must require minimal operator action and must provide a single digital output on which the decision to ship the tire or not would be automatic. For the depots that have the tire retreading mission, more sophisticated tire inspection equipment is required for both pre and post retreading inspection. The tire inspection equipment would be utilized in the pre-retread area to monitor ultrasonic readings in relation to tire casing suitability for retreading. The post retread ultrasonic inspection equipment would be used to inspect for retread quality. Operator training and test result interpretation would be required for most retread inspection with the ultrasonic equipment.

TARADCOM has focused its attention on one pulse-echo ultrasonic tester which has been developed during this program and which has the potential to satisfy both these equipment requirements. However, before our NDT evaluation plans are discussed, a brief background of prior TARADCOM programs will be presented.

BACKGROUND (Figure 2)

Since its inception, the ultrasonic tire inspection development effort has been in conjunction with and under contract to General American Research Division (GARD). In mid-1973, the effort began with laboratory tire testing with a pulse-echo tire scanner at the GARD facility in Niles, Illinois. From this initial effort a single transducer ultrasonic tire inspector, which we call the Big Red Machine, was fabricated and utilized during two separate evaluations, one at Red River Army Depot (RRAD) and the other at GARD. The GARD evaluation involved testing 500 used tires ultrasonically and correlating the measurements to peel tests and optical examinations. The results of the 500 tire test revealed the requirement to inspect the tires at

TARADCOM
ULTRASONIC TIRE INSPECTION
EQUIPMENT REQUIREMENTS

CAMPS, POST, AND STATIONS

$6,000 MAXIMUM
SEMI-SKILLED OPERATOR — MINIMAL TRAINING
AUTOMATIC SHIPMENT DECISION

DEPOTS

$10,000 MAXIMUM
SEMI-SKILLED OPERATOR — TRAINING REQUIRED
INTERPRETATION REQUIRED

FIGURE 1

TARADCOM
ULTRASONIC TIRE INSPECTION
BACKGROUND

JOINT TARADCOM AND GARD EFFORTS

LABORATORY TIRE TESTING ———→ BIG RED TOO COMPLEX,
RRAD COMMENTS   EXPENSIVE AND TIME
500 TIRE TESTS ————————→ CONSUMING

⇒ HYGROSCOPIC PROPERTIES — DEGRADATION CONCEPT
YPG ROAD TEST   — PROOF OF TIRE DEGRADATION

GARD DEVELOPMENT EFFORT

ULTRASONIC CONTACT INSPECTION TECHNIQUE GENERATION
TDM DEVELOPMENT

FIGURE 2

FIGURE 3

at both tire shoulders and the midline. This requirement and user comments from the RRAD evaluation were incorporated into an engineering prototype (Figure 3) which utilized three transducers for inspection of the shoulders and midline and a tire controller. The tire controller (Figure 4) sequenced the setting of the tire and the firing order of the transducers.

A parallel GARD effort to the 500 tire test on hygrosonic properties of or water effects on tires revealed that water absorbing tires also had low ultrasonic readings. Peel tests on these water absorbing tires verified a degraded cord structure state. This discovery inspired the birth of the degradation measurement concept. Two reports, "Ultrasonic Inspection for Tire Retreadability" and "Water Effect on Tire Maintenance Expenditure Limits," document the 500 tire test and the hygroscopic evaluations, respectively. During these evaluations pulse-echo tire inspection with the Big Red Machine was shown to be somewhat complex, expensive and too slow for high rate production testing of

retread tires; however, the degradation concept was still as yet unproven in early 1975 to abandon the program to ultrasonically inspect tires for both local and circumferential defects with Big Red.

The hypothesized concept of tire degradation had to be verified. The existence of tire degradation was substantiated during a Yuma Proving Grounds (YPG) evaluation. A modified portable sonics unit (Figure 5) was used at YPG to follow ultrasonic tire measurements as a function of tire mileage during a vehicle road test. The data from this test showed that a tire mileage increased, the average tire degradation measurement decreased for both new and retread tires (Figure 6). At this time no further consideration was given to the deployment of the big red ultrasonic system because of the hardware inspection complexities, and because the circumferential defect, that is degradation, appeared to be the tire characteristic best able to indicate casing suitability for retreading.

FIGURE 4

FIGURE 5

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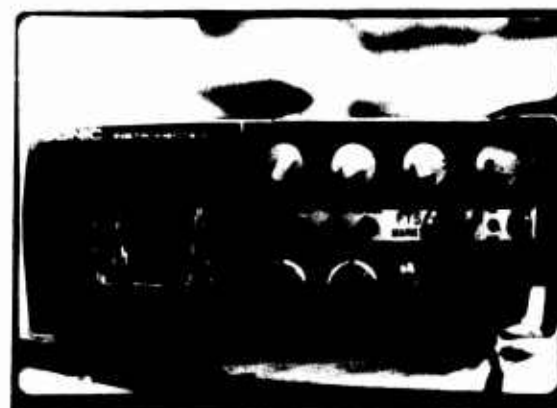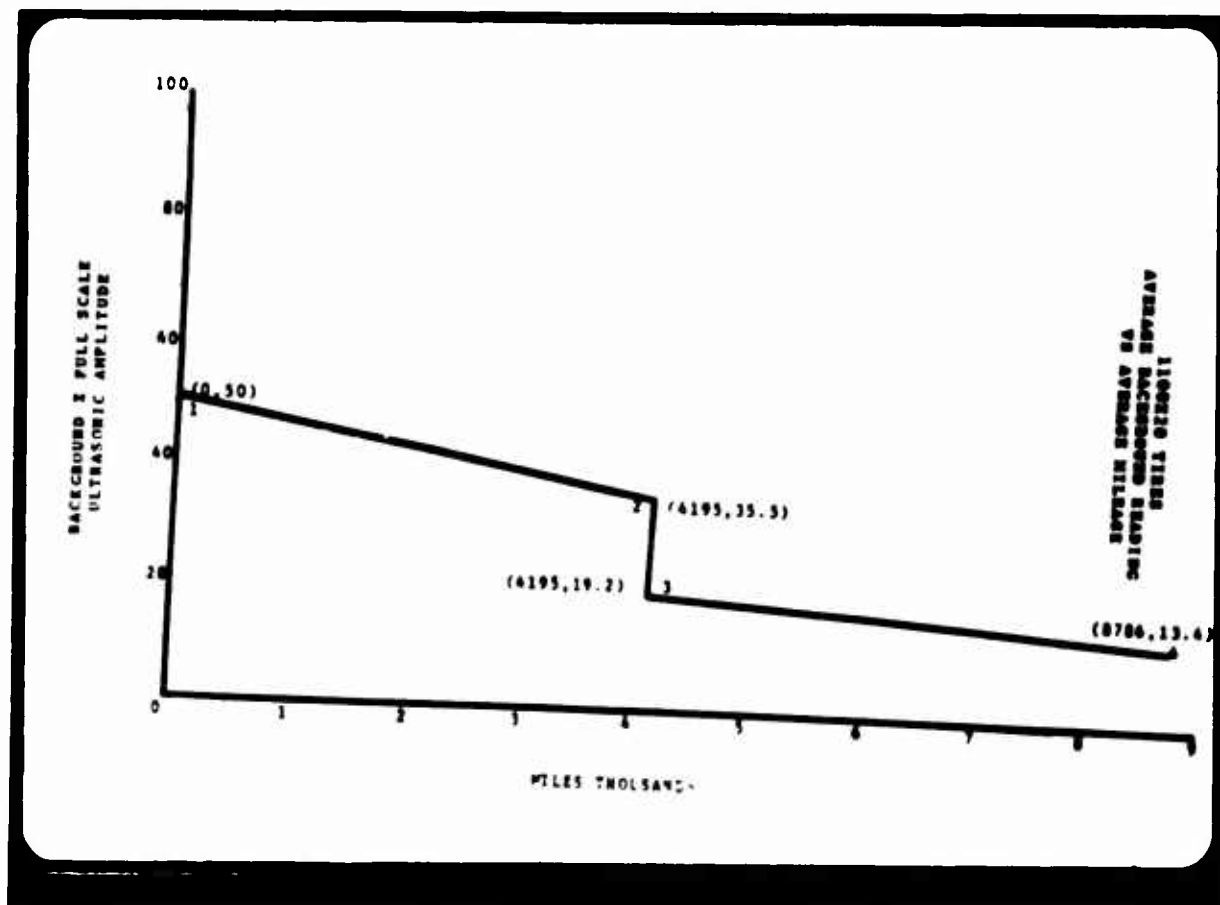
FIGURE 6

FIGURE 7

Since the time of the YPG road test, development and refinement of ultrasonic contact tire inspection techniques continued. This effort included transducer selection, generation of calibration standards, and further modification to the pulse-echo ultrasonic unit. From the contact tire inspection development effort, there evolved a commercially available single digital output tire inspection device, the tire degradation monitor (TDM) (Figure 7). The usage of the TDM became the central issue of the TARADCOM ultrasonic tire inspection program.

EVALUATION PROGRAMS

As stated, the ultrasonic equipment has evolved from the use of a pulse-echo tire scanner to a combination of modified sonics unit used in conjunction with a tire controller in the big red machine to a commercially available tire degradation monitor (TDM) with scope output capability. Therefore, the current TARADCOM programs are oriented to the evaluation of the TDM and to qualifying the degradation principle. Of the two current programs, one at RRAD and the other at YPG, each has its own objectives but both have been implemented to provide preliminary information
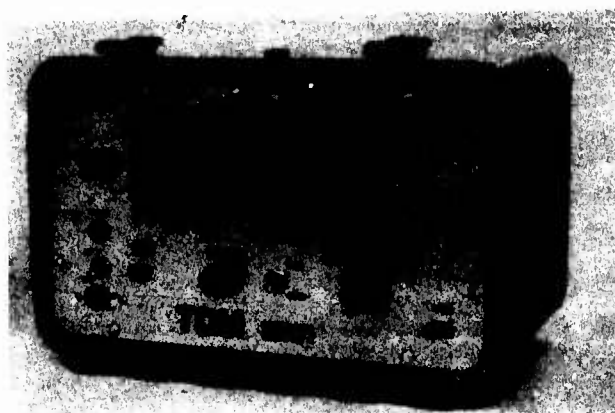
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for accomplishment of the objectives of the final ultrasonic inspection evaluation, scheduled for initiation at the Army Maintenance Plant at Ober-Ramstadt next year.

RRAD EVALUATION SUMMARY (Figure 8)

The TDM is being utilized at RRAD to determine the ultrasonic tire inspection related savings which can be attributed to reduced tire casing failures during the retreading process or to fewer rejected tires after retreading.

A program work directive (PWD) for retreading 3,000 1100 x 20 tires has been issued to RRAD, which has also been funded to ultrasonically inspect these tires. The inspection personnel have been trained in the operation of the ultrasonic tire inspection equipment and a pilot inspection program on 50 tires has been completed. Results from this pilot program will be used to minimize any problems that might have arisen during the 3,000 tire inspection program, which is anticipated to start in June 1978. The inspection data will be collected, summarized, analyzed and compiled into a final report by 1979.

YPG EVALUATION SUMMARY (Figure 9)

The evaluation will be run as a TDM pilot program to assure that the data collected at Ober-Ramstadt, to determine remaining useful life of a retread tire in relation to the tires' degradation readings, will be statistically sufficient. In addition, the tires will be holographically inspected and these readings will be compared to the ultrasonic measurements. To date, YPG has been funded to perform the evaluation and has initiated the TDM procurement action. The program will follow the sequence of events as depicted in Figure 9. Depending on the TDM procurement lead time, either a final or interim report will be prepared in December.

ULTRASONIC TIRE INSPECTION RRAD PROGRAM

OBJECTIVE —

DETERMINE SAVINGS ATTRIBUTED TO
REDUCED FAILURES DURING RETREADING
FEWER REJECTED TIRES AFTER RETREADING

STATUS — CURRENT

PWD ISSUED TO RRAD
RRAD FUNDED FOR PROGRAM
HARDWARE TRAINING COMPLETE
PILOT INSPECTION PROGRAM COMPLETE

SCHEDULED ACTIVITY

INITIATE PWD TIRE INSPECTION — JUNE 78
COLLECT AND SUMMARIZE DATA — JUNE THRU SEPT 78
ANALYZE DATA AND COMPILE RESULTS — SEPT THRU
OCT 78
COMPLETE FINAL REPORT — DEC 78

FIGURE 8

OBER-RAMSTADT EVALUATION SUMMARY (Figure 10)

There are multiple objectives for the Ober-Ramstadt evaluation. The establishment of TDM ultrasonic accept/reject criteria as well as a possible plan for grading or rating tires to maximize the remaining life expectancy represent two objectives. Determination of the TDM's inspection capability to identify casing quality, that is suitability for retreading, and cost effectiveness are two additional objectives. The final objective is to generate sufficient data to develop a draft TDM usage specification.

Currently, besides setting up the pilot TDM evaluation test plan is being prepared by General American Research Divi-

ULTRASONIC TIRE INSPECTION YPG PROGRAM

OBJECTIVE —

ESTABLISH DEGREE OF CORRELATION BETWEEN
ULTRASONIC AND HOLOGRAPHIC MEASUREMENTS AND
REMAINING USEFUL TIRE LIFE

STATUS —

YPG FUNDED TO PERFORM EVALUATION
YPG TDM PROCUREMENT INITIATED

SCHEDULED ACTIVITY —

EVALUATION MEETING FOR PLAN AND TEST INITIATION
DATA COLLECTION
ANALYZE DATA AND COMPILE RESULTS
COMPLETE FINAL REPORT

FIGURE 9

ULTRASONIC TIRE INSPECTION OBER-RAMSTADT EVALUATION

OBJECTIVES —

ESTABLISH TDM ULTRASONIC ACCEPT/REJECT CRITERIA
DETERMINE TDM EFFECTIVENESS FOR RETREAD QUALITY
INSPECTION
COST JUSTIFY ULTRASONIC INSPECTION
DEVELOP TDM USAGE SPECIFICATION

STATUS —

EVALUATION/TEST PLAN BEING PREPARED
SELECTED FIELD USER ORGANIZATION

SCHEDULED ACTIVITY

INITIATE EVALUATION — 3RD QTR 79
COLLECT AND SUMMARIZE DATA — 3RD QTR 79 TO 3RD QTR 80
ESTABLISH ACCEPT/REJECT CRITERIA — 4TH QTR 80
COMPLETE ECONOMIC ANALYSIS — 1ST QTR 81
DRAFT TDM USAGE SPECIFICATION — 2ND QTR 81

FIGURE 10

sion (GARD) and will be evaluated prior to implementation at Ober-Ramstadt. The TDM evaluation plan will include:

a. Identification of all parameters which can affect the TDM readings (i.e., ambient temperature, tire temperature, TDM probe pressure, etc.) during TDM usage for both pre and post retread tire inspection. For each of the parameters identified, a brief discussion of the parameters' affect on TDM measurements will be provided, along with the recommended experimental approach for controlling or eliminating the parameters' influence in determining the degradation reading correlation with tire casing quality or the tires' remaining useful life (i.e., eliminate affect through randomization, specifying parameter range or value, etc.).

b. Identification of what and how the various facets of the retreading process (i.e., casing repairs, buffing texture, retread rubber quality, etc.) might affect the post-retread tire degradation readings and a description of how such readings could be used to assure retread quality.

c. Identification and preparation of the recommended procedures to be followed during pre and post retread inspection with the TDM.

d. Identification of data, which must be recorded for control of the evaluation.

e. Identification of method and procedures for prescribing tire failure mode (i.e., degraded casing, manufacturing defects, road hazards, etc.) for retread tire field failures during the TDM evaluation.

f. Recommendation for TDM hardware support and maintenance during the evaluation.

The other accomplishment to date has been that the Ober-Ramstadt personnel have contacted the Commander of the 37th Transport Division about conducting the field tire life evaluation on the tires o the 37th's vehicles. At this time, it appears that the 37th Transport Division will cooperate and participate in the evaluation. Again, the evaluation is scheduled as shown in Figure 10 with the program culminating with the draft TDM usage specification for ultrasonic inspection of retread tires.

REFERENCES

"Ultrasonic Inspection for Tire Retreadability", I. R. Kraska, Nov 1974

"Water Effects on Tire Maintenance Expenditure Limits", T. A. Mathieson, April 1976

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TIRE SEALANTS: FUNCTIONAL REQUIREMENTS;
STATE OF THE ART; PROBLEM AREAS; ECONOMICS

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This paper is presented to provide a look at one of the more controversial subjects of tire maintenance—the use of internal liquid coatings for sealing, balancing, and cooling tires with a view to reducing failures and extending service life.

Over the years, there have been numerous attempts at developing tire sealants. These have ranged from combinations of turkey feathers and India rubber, to straw and condensed milk, to some of the more sophisticated polymer chemical combinations. In recent years, a variety of foam materials have been used in various applications with variable success. While these materials are effective in specific applications, the cost and limitations have restricted their use. Some areas of both Canada and the United States impose maximum speed limits on foam filled tires, usually less than 10 mph. Of primary interest to me has been the more versatile materials which, rather than fill the entire air chamber, simply provide various degrees of coatings to the inner surfaces of the tire. A review of past literature, including issued patents, and discussions with almost anyone in the tire industry quickly indicates that there have been some rather unfortunate experiences with these materials. On the other hand, there have been some excellent experiences, with some products.

Basically, past failures can be divided into two major groups, Product and Application.

PRODUCT: There have been many products which simply failed to perform. Some of the bad habits have been:

    (a) Freezing
    (b) Damage to the tire or rim materials
    (c) Deterioration forming rubbery lumps
    (d) Failure to seal even minor punctures

APPLICATION: As with any product there are limitations. Unfortunately, some overzealous salesman and/or overanxious customers tend to ignore those limitations and try to use the wrong product for the wrong application. At best the results are disappointing, at worst, disastrous.

As with anything else, a good product in the proper application, with realistic expectations, will perform satisfactorily.

FUNCTIONAL REQUIREMENTS: A puncture sealant has to meet several basic requirements, some of which tend to be incompatible.

1. It must coat the entering, puncturing object and provide an air tight seal. When the puncturing object is thrown out, or otherwise removed, the sealant must flow into or over the aperture and seal the hole.

2. The sealant must stay in place across the full tread, notwithstanding the 160 g's of centrifugal force in the shoulders of a truck tire traveling at 60 mph.

3. It must be stable and able to function over a wide range of ambient temperatures.

4. It must either assist in balancing the tire or have little or no effect on balance.

5. It must be compatible with tire and rim components.

6. It must be easily removeable prior to retreading.

7. It must be easily and economically applied.

This paper will be limited primarily to the use of sealants in truck and earthmover type tires. Passenger and light truck tires present special problems with balance. Low pressure, short radius, high speed tires, are subject to rather extreme deformation in operation. The more viscous fibre based sealants can adversely affect balance in these tires. While this does not necessarily occur in every case, the results are inconsistent enough to warrant avoidance of passenger type tires with viscous fibre based materials. There are, however, several low viscosity non-fibrous sealants which have little or no affect on balance which can be successfully used to seal small leaks in passenger and light truck tires. Some of these products do provide excellent protection against slow leaks caused by rubber porosity, rim/bead leaks, and small pinhole punctures.

SEALANT: In attempting to define an effective sealant, it is necessary to define:

1. What types of air leakage are to be stopped?

2. What level of performance is acceptable?
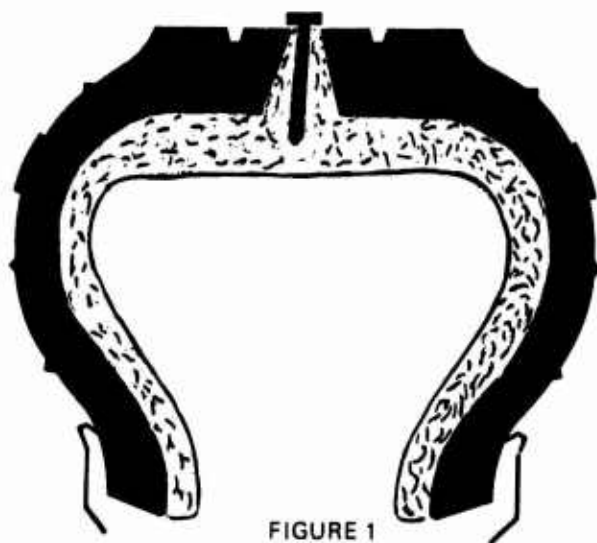
FIGURE 1
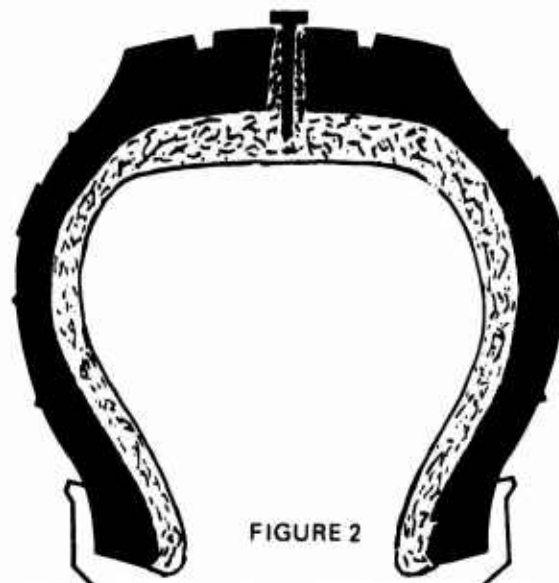
FIGURE 2

Air leakage can come from a variety of sources including:

(a) Punctures
(b) Rim/bead interface imperfections
(c) Porous or flawed inner liners or tubes
(d) Rim imperfections, i.e., pinholes at welds.

Acceptable performance level is usually an individual matter, primarily economic in nature. In some operations, a flat tire is only a slight inconvenience and a relatively rare occurrence. These operations are indeed rare. In most operations, a flat tire can mean substantial expense, and in some cases, disaster.

We have developed, with a great deal of help from a large number of companies and organizations a product which performs particularly well in a wide variety of applications. The material is a short fibred mixture in colloidal suspension with anti-freeze, adhesives, lubricants, diluant and corrosion inhibitors, among other ingredients.
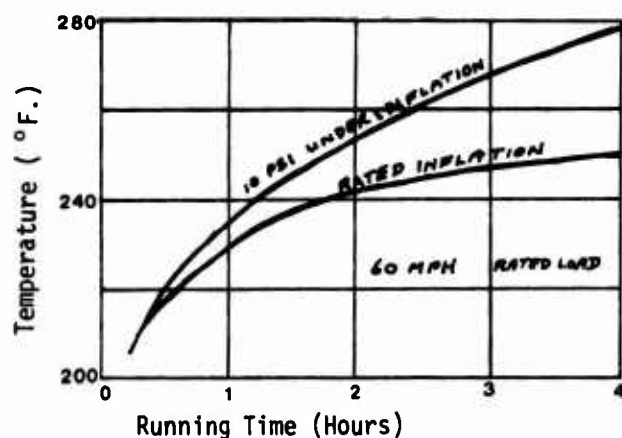
TIRE TEMPERATURE
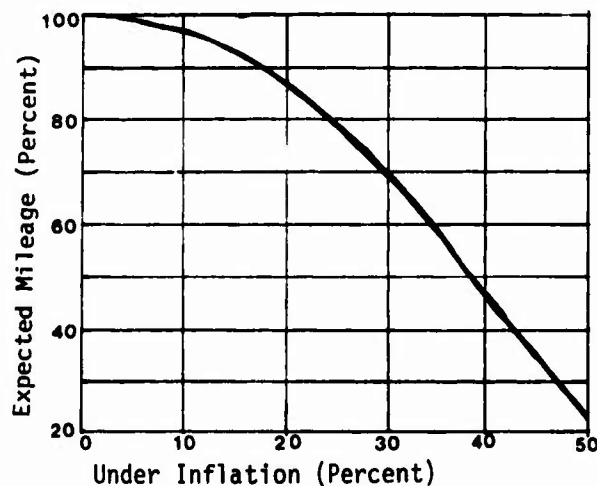
EFFECT OF INFLATION ON MILEAGE

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It would appear that for many truck tire operations, the 90 percentile puncturing object is typically represented by a 12 gauge nail (0.100" diameter). As part of our continuing evaluation program, testing was conducted on the product by Smithers Scientific Services, Inc. A copy of their report is included in this paper.

Testing has been directed at achieving 100% sealing of tread area punctures by the 90 percentile object. Our objective was to achieve a 90% reduction in the incidence of flat tires in the average highway operation using tubeless tires.

While the exact mechanics of why this material effectively seals most punctures are theoretical, it would appear that FIG. 1, Fluid carrying fibre and filler enters the puncture as the hole in the rubber spreads under load. An adhesive coats the sides of the hole and the fibre and filler begin to adhere. FIG. 2, the fluid is squeezed out as the tire rolls off the load point depositing the fibre and filler. Repeated rolling, under load, deposits more fibre and filler until a solid plug is formed. This process is repeated when the nail is removed. The tire must roll under load after the puncture to assure proper sealing. Under actual operating conditions, this entire process is almost instantaneous.

One of the most frequent causes of tire failure is underinflation. An underinflated tire runs hotter, wears faster, and is much more subject to being punctured. Maintenance of the specified inflation pressure is vital for full service life.

Rubber is relatively porous. Most tires will lose air over a period of time, some faster than others. We have found that a good tire sealant can reduce or virtually eliminate that porosity and can act as an aid in maintaining the specified inflation pressure. We live in a very imperfect world and even the best manufactured rims and tires are subject to frequent punishment from missed hammer blows and careless handling, etc. Rim and bead leaks are frequent. A good sealant can compensate for many of these problems.

Tread separations, particularly with tubeless retreads, are a major headache which can, in many cases, be avoided. These separations frequently are caused by small holes through the inner liner which are missed in the pre-retread inspection. High pressure air passes through the hole to the new rubber of the tread, FIG. 3. Its escape route cut off, it spreads out between the old casing and the new tread until separation occurs. By effectively sealing these small liner holes, the pressure on the new tread can be reduced so that full service life is achieved without incident. In my opinion, given the frequency and severity of this problem, the use of an effective sealant in tubeless retreads should be mandatory.

If it is found that the sealing characteristics are not as expected, check for:

1. Oily or lubricated puncturing object
2. Lack of sealant in the tire.
3. Sidewall puncture. The rubber continues to work to break the seal.
4. Rips, tears, or cord damage.
5. Stretched rubber, sometimes found in overinflated tubes.
6. Proper tube size for tire.
7. Puncturing object larger than 0.1" diameter.

A question has been raised on the effect of leaving nails in the tire and their possible effect of working to enlarge the hole. We have seen no instance where this problem has, in fact, occurred. We do, however, recommend regular tire inspection and removal of these nails. It is important to keep in perspective the maximum size of hole that a sealant can plug. If indeed the hole were enlarged, the tire would simply go flat long before irreparable damage were done. What seems to actually occur is that the vehicle makes it to its next inspection where service is more easily and economically carried out. Routine in-shop service is invariably less expensive than on-the-road service calls. In the case of a major puncture, the leakage is usually slower, allowing the driver to maintain control of the vehicle for a safe stop.

There has also been concern about the effect of sealants on steel belted radial tires. Some fears have been raised that moisture could attack the belts causing separation.

To put this into perspective, it must be realized that the majority of punctures are stopped by these belts. That is their primary purpose. These incomplete penetrations can
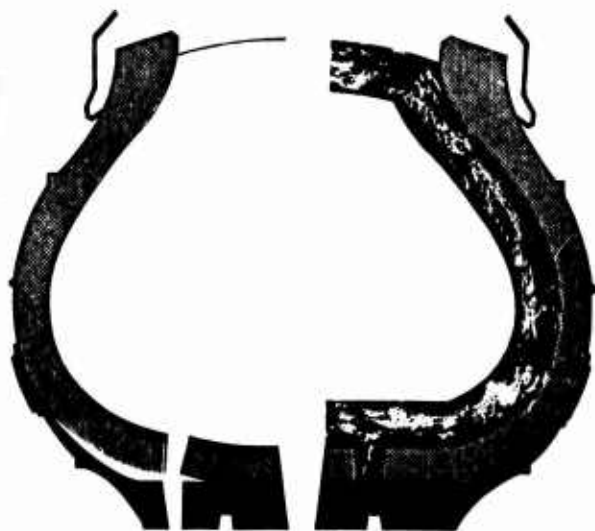

FIGURE 3

allow outside moisture to reach the belts by capillary action. This outside moisture is usually highly contaminated and has strong corrosive action. The effect of a tire cooling while moist on the outside can aggravate this problem and the moisture can penetrate the rubber sidewalls directly or through vent holes.

A good sealant contains effective corrosion inhibitors for protection of both the rim and steel belts. A complete penetration through the belts to the air chamber allows corrosion inhibiting material to protect the belts from deterioration. In short, a complete penetration is safer.

Concern has been raised that sealants might pass through the inner liner to attack the belts. In the case of severely defective liner this would seem possible. However, a good sealant will form its own liner effectively compensating for the original flawed liner. It is interesting to note the calcium and water ballasting charts produced by manufacturers of steel belted tires.

The puncture sealing capability of a tire sealant will, of course, vary between tube type and tubeless tires. The greatest efficiency is in tubeless tires, for obvious reasons. However, we have had exceptional success with tubetype tires in highway fleet operations. While the material will seal some tube type punctures, we feel that the primary reduction in flat tires has come from the material helping to maintain the correct inflation pressure. A properly inflated tire does not tend to pick up nails etc. as easily as a hotter, underinflated tire. The sealant may be preventing the problem in the first place, rather than correcting it after the fact. Whatever the reason, controlled fleet tests show substantial improvement with the product.

Sealing capability will also vary between highway and the slower Off-road tires. The higher speed highway tires tend to have concentrated protection in the tread surface area, the area most likely to be punctured. We have noted, that a thin moist film is retained on the sidewalls, and in the rim/bead area. When the tire is moving at lower speeds it tends to allow the material to coat these areas chich, of course, can help seal rim/bead leaks and porosity leaks. The much slower moving earthmover tire tends to spread the material more evenly throughout.

BALANCE: Out-of balance highway tires can be costly. These tires bounce and scuff the tread away as they hit the road. This bouncing reduces tread life and can impair driver control. Vibration also causes excessive bearing wear, chassis damage, and dangerous driver fatigue. With conventional lead weight balancing methods, dual tires and wide floatation tires are almost impossible to balance. A liquid sealant of the correct viscosity can hydrodynamically balance highway truck tires for longer tread life.

In any rotating body with an unequal weight distribution, the center of gravity is closer to the heavy side of the body.

This holds true in an unbalanced tire assembly. Since the tire will try to rotate about its center of gravity, which is toward the heavy side of the tire, the light side of the tire will travel through a longer distance. Since Centripetal force, $C=MV^2/R$, where M is the Mass at a point, V is the Velocity of the point, and R is the distance from the center of Rotation; therefore, on the light side of the tire the centripetal force is greater. Because of the larger centripetal force on the light side, more fluid will flow to this area. This action returns the center of gravity to the center of the wheel assembly, where it belongs.

The product's ability to remain mobile is vital. This allows it to shift as the tire wears or road and load conditions change. It would appear that the viscosity of the product is an important factor in its ability to act as a balancing agent. If the viscosity is too low, a confused wave action can be set up reducing or eliminating its ability to act as a balancer. If the viscosity is too high, the material could pool in one place after standing for an extended period and be difficult to redistribute within the tire. It is for these reasons that adequate freezing point depression is essential and that product stability is important. In some products there has been a tendency to use some natural or synthetic cross-linking polymer gums which under extended heat conditions have tended to cure and ball up in the tires. This, of course, aids neither balance nor sealing. The use of very long fibre can also aggravate the tendence to ball up. While the viscosity tolerance is relatively wide, it certainly is a consideration.

A curious condition has been noted in assessing the balance capabilities of liquid sealants. As yet we are uncertain as to the reason for this condition. In mechanical spin-balance testing, the tire may or may not show as balanced. In over the road testing, vibration analysis will indicate a consistently balanced condition. The ability of liquid to balance is directly proportional to the quantity installed. In a 10.00 x 20 tire, lead weights are placed approximately 10 inches from the center of the wheel. A liquid in the tire is approximately 20 inches from the center of the wheel. Therefore, half as much liquid weight will do the same job as the lead weights. As the total liquid is widely distributed, only a small part of the liquid actually acts as a balancer. We have found with 10.00 x 20 tires that 32 ounces of sealant can provide balancing the equivalent of 12 to 14 ounces of lead weight. It can be assumed that 6 to 7 ounces of liquid is actually used for balance, or roughly 20% of the installed quantity. Increasing the installed quantity helps, within limits. For a properly mounted, reasonable quality 10.00 x 20 tire, 32 to 40 ounces of sealant should normally be adequate to achieve proper balancing. In tubeless tires with exceptionally heavy liner ribbing, increased quantities may be needed to allow the material to flow over the ribbing. With tube type tires, care should be taken in mounting the tube in the tire. Folds or creases can act as a dam, preventing the free flow of the liquid. This occasionally happens where an oversized or stretched tube is used.

While many fleet operations balance the steering axle tires, most do not even try to balance either the drives or the trailer tires. This results in a great waste of potential service life on the unbalanced tires. While balancing these drive and trailer tires with lead weights on the rims is extremely difficult, if not almost impossible, liquid balancing provides an inexpensive, quick and easy solution to the problem. Because the liquid automatically seats itself in actual operation, the tires can run consistently balanced for extended tread life.

On the initial installation, it will take a few miles of driving to distribute the fluid within the tire. Subsequent runs should balance within a few hundred yards. Liquid balancing can be used in truck and bus tires 9.00 x 20 and larger. We have also been successful with the smaller heavy duty tires used on auto carrier trailers which run at substantially higher inflation pressures than passenger and light truck tires.

It is important to recognize that not all vibration problems are tire balance related. Where the problem is actually a tire balance problem, a liquid balancer will normally be the solution.

COOLS: Internal liquids can have a cooling effect on the tire. It must be noted that when using a liquid coolant, the contained air temperature may or may not be lowered. Contained air temperature is just that—a measurement of the temperature of the air within the tire. Our concern is with the temperature of specific locations within the tire itself. Because of the variations of internal and external friction on various parts of the tire, and since rubber is a relatively poor conductor of heat, there are substantial differences in temperature at different points within the tire. An internal liquid coating of a good heat conducting material, such as a glycol, can act as a thermal conductor, transferring heat from areas of higher temperature to areas of lower temperature. Ideally, this thermal transfer will keep the temperature of the hot spots below the critical level at which the tire will fail. Thermal conductivity varies with the properties of the liquid, the thickness of the coating, and the extent of the coating. The effect of thermal conductivity tends to be greater in earthmover type tires because of the larger areas of the side wall that are coated. While a slow moving tire tends to be more evenly coated throughout, the high centripital forces generated by highway vehicles tend to concentrate the bulk of the material in the tread area.

A secondary, and perhaps more important, cooling effect is obtained through correct inflation pressure maintenance. An underinflated tire tends to operate hotter. Increased internal flexing heats the rubber making it much more subject to wear.

The use of a good sealant assists in pressure maintenance which in actual operations means that the tires run cooler than the normally underinflated tires.

As discussed earlier, it is important that the liquid be easily removeable prior to retreading. Water soluble materials are ideal for facilitating removal from a puncture area which must be repaired.

Ease of installation is also important. The majority of available sealants are injected through the valve stem after the valve core has been removed. Hand pumps capable of working against the tire's internal air pressure are available and normal installation in a truck tire can usually be accomplished in less than five minutes without removing the tire from the vehicle or deflating the tire completely.

QUANTITY CALCULATION: The quantity of sealant required will depend somewhat on size of the puncture to be sealed, the size of the tire, and the type of operation in which the tire is to be used. If it can be assumed that a sealant layer of 0.050" would be adequate to seal the more normal punctures, then the quantity needed can easily be computed based upon known tire dimensions. Typically, a 10.00R20 steel radial, load range G truck tire has a measured O.D. of 41.50" and a toe-to-toe internal perimeter of 26.9" when mounted on a 7.5" wide rim. The tire measures 10.7" in width at its widest point and has a tread radius of approximately 20.00".

The necessary quantity of sealant required can then be calculated as follows:

$$TSV = (BB) \ (CIMM) \ (0.050)$$

Theoretical Sealant Volume = Bead toe-to-Bead toe measurement x Circumferential Internal Mean Measurement x 0.050"

where   Circumferential Internal Mean Measurement =
O.D. $- 2(\frac{1}{2}$ section height)

Therefore $CIMM = 41.5 - \frac{(10.75)}{2} \ 3.1417 \ = \ 96.6$

$TSV = (96.6) \ (26.9) \ (0.050)$
$TSV = 129.94$ cubic inches
Knowing that 1.805 cubic inches =
then
$\frac{129.94}{1.805} \ = \ 71.96$ oz.

$TSV = 71.96$ oz.

Unfortunately, in highway service the sealant material will not stay along the sidewalls due to the action of centrifugal force as the tire rolls. Therefore, the calculation should only direct itself to that area of the tread which is more likely to be subjected to punctures. In this instance, an 11" width should be used instead of the bead toe-to-bead toe measurement of 26.9" (Tread width of 8.0" + 1.5" each shoulder + 11")

Recomputing we obtain:

$$TSV = 96.6 \times 11 \times .050 = 53.1 \text{ cubic inches}$$
$$TSV = 52.1/1.805 = 29.4 \text{ oz.}$$
$$TSV = 29.4 \text{ oz.}$$

Therefore, 29.4 oz. of sealant would theoretically seal adequately.

We have theorized that a sealant layer of 0.050" in thickness will be adequate within the performance aspects of the tire and the environment in which a tire operates. Based upon many variables, actual thickness of a sealant material may vary to almost three times the 0.050" suggested.

Under actual testing, it was determined that the best results were obtained at 40 ounces of sealant in an 11 R 22.5 tire. Recomputing, this would place the sealant thickness at about 0.07".

An alternate and simplified approximation of the desired quantity can be roughly calculated as follows:

Highway Operations – Quantity in Ounces = 0.109 (A(A+B))

Where
A = Section Width
B = Rim Diameter

e.g. 11 - 22.5

0.109 x 11 (11 + 22.5) = 40 ounces

OFF-THE-ROAD OPERATIONS

In Off-The-Road Tires, centrifugal force tends to be much less a factor, and the sealant tends to spread out and more evenly coat the sidewalls. While this has obvious benefits in sealing sidewall leaks and rim/bead leaks, it does deprive the inner tread surface area of the liner of adequate protection. To provide this protection, larger quantities of sealant are needed. It is for these reasons that we recommend at least doubling the quantities recommended for a highway service tire of the equivalent size. Converting the above rough formula to earthmover type tires etc. the O.T.R. formula would be:

0.22 (A (A+B)) = Quantity in Ounces

e.g. 20.5 - 25

0.22 x 20.5 x (20.5 + 25) = 205 Ounces

As balance is normally not a factor in O.T.R. tires, there are no minimum size restrictions as in the case of highway service tires. However, as sealing capability is normally of the greatest concern, it is best to restrict a sealant's O.T.R. use to tubeless tires.

While the performance of a sealant will vary greatly depending on type of operation and the standards of tire maintenance in that operation, the results are often difficult to believe. In some operations, flat tires are virtually eliminated. In others, the incidence of flat tires is reduced to an acceptable level. Operations using tubeless retreaded tires have reported virtual elimination of separation failures. In testing by Smithers Scientific Services, 11 R 22.5 tires with eight 0.100" diameter nail holes in each tire successfully completed the Federal Motor Vehicle Safety Standard 119 endurance requirements. There is no question as to what would have happened to those tires without a sealant installed. Many tires which would have been scrapped because of defective liners have achieved full normal service life. In highway service operations, service life extension has ranged from 16% to over 40%.

There are many benefits to the proper use of sealants in many applications. These products are not meant to be a substitute for a good maintenance program. They are a valuable aid to that program. However, I must admit that our results are best where the maintenance program is poorest. The need for good sealants has been recognized by several of the tire manufacturers. Some currently use our product to help improve competitive performance. Some use it to help correct minor manufacturing problems, such as liner flaws. Some companies, such as Michelin, are developing their own formulations. I was rather amused to note the issuance of a sealant patent to Michelin in Britain.

Essentially, tire sealants can be an inexpensive problem. It is a simple fact that a properly inflated, balanced, cool running tire lasts longer and is less subject to failure. A good sealant can help achieve that ideal and allow the operator to get full value from his tire investment.

	FIBRE BASED Flat Guard*	NON-FIBROUS Micro-Seal*	FOAM
Seals Punctures (0.10" Dia.)	YES	NO	YES
Seals Porosity, Rim/Bead leaks	YES	YES	N/A
Balancing	YES	NO	NO
Cooling	YES	YES	NO
Truck Tubeless (Highway)	YES	YES	NO
Truck Tube Type (Highway)	YES	YES	N/A
O.T.R. Tubeless	YES	YES	YES
O.T.R. Tube Type	NO	YES	N/A
Passenger & Light Truck	NO	YES	NO
Legal Speed Limits Over 50 mph	YES	YES	NO

*Flat Guard and Micro-Seal are Trade Marks of Ti'Seco Ltd.

Care must be taken to assure that the selected commercial product has the required performance characteristics and that it is used in the proper application.

Because of the wide variety of applications, controlled testing for suitability is important.

CORROSION CONTROL

Flat Guard has undergone the most extensive corrosion control testing at the University of Western Ontario Engineering Faculty, Tire Manufacturers, and in our own facilities.

PRIMARY PROCEDURE

The numerical values of the corrosion rate were determined by linear polarization technique.

APPARATUS

Wenking Potentiostat
300-400 Ml. Flat Guard Mix
Graphite Counter Electrode
Calomel Reference Electrode
Provision for stirring and heating

Polarization resistance determinations were made with 2 and 4 mV polarizations. In the calculations a factor of 0.026 was used whether or not the electrode was active. Several full polarizations were measured.

Eight coupon specimens were partially immersed in Flat Guard mixes in loosely sealed containers. The containers were at room temperature and a few drops of water added as required to keep the mix wet. These specimens were used to confirm the polarization resistance measurements and to test for water line corrosion.

SUMMARY OF RESULTS

		Corrosion Rate IPY
1. STEEL	26 C (79F)	Passive, Specimen Shiny on Removal
	80 C (175F)	Passive, Specimen Shiny on Removal
2. BRASS	26 C (79F)	0.001"/Year
	103 C (243F)	0.007"/Year
3. ALUMINUM	26 C (79F)	Less Than .001"/Year
(6061-T6)	80 C (175F)	0.002"/Year

The fact that Aluminum reacts slightly is beneficial in that it makes the alloy less susceptable to other forms of local attack.

Attempts to induce pitting corrosion and stress corrosion with Flat Guard were unsuccessful.

Flat Guard will not damage the materials used in tires or rims.

REFERENCES

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2. "IMPROVEMENTS IN PNEUMATIC TIRES". Patent Specification 1 496 498, British Patent Office, granted to Michelin et Cie (Compagnie General des Establissements Michelin.

3. United States Patent Office, PATENTS #:

587,982	1,062,525	1,233,753
598,324	1,117,526	1,383,572
599,115	1,690,051	1,467,065
661,124	2,120,379	1,561,332
715,784	2,141,959	1,896,611
825,930	2,286,963	2,003,112
836,569	3,881,943	2,355,977
892,521	1,128,282	2,357,650
981,429	1,143,152	3,676,381

4. "DO YOU UNDERSTAND GALVANIC CORROSION?", C.W. Hawk Jr., Chemical Engineering, June 6, 1977.

5. "HOW CORROSION THEORY RELATES TO COATINGS – PART 11", D.M. Berger, Chemical Engineering, Aug. 29, 1977.

6. "POWER CONSUMPTION OF TIRES RELATED TO HOW THEY ARE USED", W.K. Klamp, Conference Proceedings, Tire Rolling Losses and Fuel Economy – An R & D Workshop, Oct. 18-20, 1977, Transportation System Center, Cambridge, MA.

7. "WATER EFFECTS ON TIRE RELIABILITY", L. Ash and R. Johnson, Second Symposium on Nondestructive Testing of Tires, Oct. 1-3, 1974, Atlanta, Georgia. Pub by Army Materials and Mechanics Research Center, Watertown, MA.

QUESTIONS & ANSWERS

Q: Speaking as a hostile member of the audience, for twelve years I've been with Firestone. For twelve years one of my responsibilities has been tire sealants and everyone comes around and gives the same pitch as you do. They seal the tire. We run the tires on test and we find sometimes they seal, sometimes they don't. We find with tire sealants we have comments like OK they run in testing

TRANSPORT FLEET #1

Test run on 6 new White "Road Boss" tractors for highway transport between Toronto, North Bay, and Timmins. The units travelled on both flat divided highways and high crown roads. 30 tube type 10.00X20 tires on Units#6521, 6522, and 6527 were treated with Flat Guard. 30 tube type 10.00X20 tires on Units #6511, 6512, and 6513 were not treated and were used as a control group. In addition, some trailer units were treated and compared to other untreated trailers.

TRACTORS TREATED WITH FLAT GUARD
30 tires run 1,897,440 tire miles ----- 2 FLAT TIRES (1 flat caused by valve cap left between tire and tube)

TRACTORS UNTREATED CONTROL GROUP
30 tires run 2,481,210 tire miles ---- 13 FLAT TIRES

TREATED tires averaged 948,720 tire miles per flat.(6.7% of tires had flats)

UNTREATED tires averaged 190,862 tire miles per flat.(43.3% of tires had flats)

THEREFORE: 80% FEWER FLATS WITH FLAT GUARD. (adjusted mileage)

TRAILERS
TREATED with Flat Guard ---- 34 tires ---- 1 FLAT TIRE.(2.9% had flats)
UNTREATED CONTROL ---------- 84 tires ---- 22 FLAT TIRES (26.2% had flats)

THEREFORE: 88.8% FEWER FLATS WITH FLAT GUARD

LONGER TERM TESTING INDICATED AN INCREASE IN TREAD SERVICE LIFE OF OVER 20%

ON THE TREATED TIRES.

COST / BENEFIT RELATIONSHIP IN THIS FLEET

ASSUME:
Tractor @ 10 tires + trailer @ 8 tires = 18 tires / tractor-trailer unit.
Tire Cost @ $150 / tire
Balancing Steering Axle with lead weights on Untreated unit @ $20.
Flat Guard Treatment Cost @ $7.00 / tire = $126 / tractor-trailer unit.

		(Industry
Downtime Cost per Flat	$100	$400 Average)
TREATED UNIT		
Tractor 2 flats/30 tires X 10 tires	$ 67	$268
Trailer 1 flat/34 tires X 8 tires	24	96
Flat Guard treatment cost $7 X 18 tires	126	126
SUB-TOTAL (A)	$217	$490
UNTREATED UNIT		
Tractor 13 flats/30 tires X 10 tires	$430	$1720
Trailer 22 flats/84 tires X 8 tires	210	840
Balancing steering axle with lead weights	20	20
SUB-TOTAL (B)	$660	$2580
DOWNTIME COST/BENEFIT WITH FLAT GUARD (B - A)	$443	$2090
Value of 20% increased tread service life on		
treated unit.($150 X 20% X 18 tires)	540	540
NET SAVINGS ON FLAT GUARD TREATED UNIT	$983	$2630
NET RETURN ON INVESTMENT AFTER COST	780%	2087%
Overall average net savings per tire per full		
tractor-trailer unit	$54.61	$146.11

FLAT GUARD

PERFORMANCE NET BENEFIT PER 100 TIRES

GIVEN: 11-22.5 TIRE PRICE @ $150.00

            DOWNTIME   = $100.00/ FLAT

            FLAT GUARD COST = $ 8.75/ TIRE 11-22.5

o/o INCREASED TREAD SERVICE LIFE

	0	5	10	15	20	25	30	35	40	45	50
0	-675	75	825	1575	2325	3075	3825	4575	5325	6075	6825
2	-475	275	1025	1775	2525	3275	4025	4775	5525	6275	7025
4	-275	475	1225	1975	2725	3475	4225	4975	5725	6475	7225
6	-75	675	1425	2175	2925	3675	4425	5175	5925	6675	7425
8	125	875	1625	2375	3125	3875	4625	5375	6125	6875	7625
10	325	1075	1825	2575	3325	4075	4825	5575	6325	7075	7825
15	825	1575	2325	3075	3825	4575	5325	6075	6825	7575	8325
20	1325	2075	2825	3575	4325	5075	5825	6575	7325	8075	8825
25	1825	2575	3325	4075	4825	5575	6325	7075	7825	8575	9325
30	2325	3075	3825	4575	5325	6075	6825	7575	8325	9075	9825
35	2825	3575	4325	5075	5825	6575	7325	8075	8825	9575	10325
40	3325	4075	4825	5575	6325	7075	7825	8575	9325	10075	10825
45	3825	4575	5325	6075	6825	7575	8325	9075	9825	10575	11325
50	4325	5075	5825	6575	7325	8075	8825	9575	10325	11075	11825

NUMBER OF FLATS PREVENTED / 100 TIRES

EG.: IF 35 FLATS PREVENTED AND 30% TREAD SERVICE LIFE INCREASE THE NET SAVING WOULD BE $7,325.00 PER 100 TIRES.

laboratories and these tires would assuredly fail if they did not have the sealants in them. However, I've had many, many examples where tires have run perfectly well with nails in them and when they've been removed, the retreaders will find five nails in the tire was obviously holding air. I am really wondering what is different about your sealant? I am very interested in sealants and have spent so much of the company's money and it bothers me when someone gets up and says they have developed one that works. Frankly, I've wasted a hell of a lot of my company's money and my conscience bothers me a lot. I'm willing to test someone else's but I'd like to know what is different about it.

A: I hate to get a hostile member of the audience excited but Firestone approved our product; they tested it several years ago. Quite a number of their branch operations throughout Canada have been using the product for the last four years.

Q: Firestone in Canada?

A: Firestone in Akron tested the product and accepted it as nonharmful to the tires and to the rims. As far as the other testing that you've done down there, I really don't know.

Q: That testing would have been accomplished in my department, and I don't know of any tests.

A: You'd better talk to John Byers.

Q: OK, I'll talk to John Byers.

A: I also have a copy of the letter from John on the product.

Q: You said that Michelin has a patent on it.

A: Yes, they are using the ingredients in our formula.

Q: Why don't you have a patent on your formula?

A: Because we withdrew our patent application. The patent was granted, and we withdrew it just prior to publication. It's not exactly the same formula, but one of the things we've recognized in the chemical industry is that it is one of the worst industries for patent piracy. We prefer the trade secret route. So far we've had four different tire companies and other companies trying to break our formula and they haven't been able to do it yet. If somebody can do it, they're welcome to it.

CHAPTER IV

WORKING GROUP REPORTS

Charles P. Merhib, Moderator

ULTRASONIC WORKING GROUP REPORT

I. Kraska, Chairman
GARD/GATX
7949 N. Natchez
Chicago, IL

The meeting of the Ultrasonic Working Group started with a review of the ultrasonic tire testing methods, who was doing what in development and the use of the various techniques. John Burche reported on Bandag's efforts in developing the air couple sonic system. Irving Kraska reported on the ultrasonic immersion system and Dick Johnson fielded questions on the GARD TDM. Several inquiries were made about the future plans for the use of the DOT pulse-echo system. Unfortunately, there was no DOT representative present to field these inquiries. We discussed at length the tire depradation monitor, its use in retreading, quality assurance, and new tire development. Various participants described their experience with the TDM. Mr. Clerger of Armstrong Rubber described their interest in monitoring their new tires and Dick Baumgardner of Firestone talked about his experiences with the unit. The general opinion seemed to be that the use of the contact ultrasonic pulse-echo system seems to be a reality for degradation and QC purposes. The successful uses of the TDM in the retread shops is somewhat dependent on the interests of the operator and knowledge and use of the tires. This is practical for the independent retreader but more difficult for the tire manufacturers' retread plants. More in-plant experience needs to be gained in manufacturers' retread shops, in human factors, and job motivation area. The use of contact pulse-echo ultrasonics in new tire development seems to be practical and its full potential has not yet been realized. Steel-belted radials, at the retread plant level, separations are still a problem. This problem may be a good application for the thru transmission or the 360° scanning pulse-echo systems. Currently, no such systems are available, however, several manufacturers are working on them. Truck tires, the use of pulse-echo for nylon and steel: the capability seems to be there and in fact it is in use at the retread level, and since military tires resemble commercial truck tires, the use of ultrasonics

seems very practical and is currently being pursued by the Army. The use of ultrasonics for aircraft tires has been shown feasible, but not enough work has been done to prove that it is practical. If degradation is found to be practical, for aircraft tires, it could be very cost effective and could be used as a day-to-day routine on vehicle inspection procedure. Further research in ultrasonics should be pursued. Ultrasonics is one of the few NDT methods shown to be fast enough for production use. Again, it seems to be the consensus of all the working groups that a very important point brought out was the encouragement of more cooperation and exchange of information both research and use between the tire manufacturers and equipment manufacturers working in the ultrasonic field. More important are the results in overall use is needed.

Q: Can NDT be used for on-the-vehicle inspection? Has there been a history of somebody using it?
A: Yes, we've used it both on military applications and the commercial retread plant. We actually monitored some of the tire testing that we've done out at the Yuma Proving Grounds with actual on-vehicle inspection. For example, we're running the 151 jeep and prior to the driver going out, we inspected all four tires. We told him to be careful, since one was defective and indeed two hours later he came back with a flat tire. The tire had actually failed. We have run both the 2½ ton truck and a jeep in the Chicago area. We piggybacked some other tests. They had some diagnostic equipment on them for some 20,000 odd miles and we did our on vehicle inspection every 2,000 miles. In addition, we did go to a retread plant, a commercial retreader, who was experimenting with retreading. What he wanted to do was take just the whole wheel off and retread it without demounting it. Just drive the truck in, remove

the wheel from the vehicle, retread it, and stick it back on. We did do our tire test on the vehicle but it was done before demounting the tire.

Q: Is there a very significant difference between the signal readout?

A: Actually what happens is that you get better reflectivity off the ply layers because of the inflation pressures in the tire.

Q: How long does it take to run the test?

A: Tests like this take about thirty seconds as long as you're not documenting anything. Once you start documenting then it takes a lot longer, but we just simply make the inspection.

HOLOGRAPHY WORKING GROUP REPORT

R. M. Grant
Industrial Holographics, Inc.
Auburn Heights, MI

The Holography Committee consisted of over thirty people, and I think a brief comment should be made before trying to summarize the opinion of that committee. In view of the recent DC-10 accident which occurred in Los Angeles and which was caused by tire failure, many of the people on the committee who are in the field of tire manufacture and tire testing had that particular accident on their minds constantly during the last few weeks. Therefore, much of our discussions centered around what the basic concept/reject criteria are in the aircraft tire industry.

Carroll Shaver, from Air Treads, served as a focal part of that conversation and did a very excellent job of summarizing for us the commercial testing which is presently being done in industry by and large on commercial aircraft tires. Approximately three quarters of the time was then spent on the concerns regarding the reliability of the accept/reject criteria that is presently being used in commercial testing, and an evaluation of whether that criteria was realistic.

In the past, the criteria, had been typically one half inch separation diameter, (actually $\frac{1}{2} \pm \frac{1}{4}$). Experience has shown over the recent past that acceptance or rejection of a tire due to the existence of a $\frac{1}{2}$ inch or (smaller) separation is much too tight a criteria. Recent commercial airline tires are being accepted or rejected on a criteria of allowing separations up to one inch to pass in the central crown region of the tire; or rejection for any size separation when the carcass is extremely weak and fatigued. In other words, the newer accept/reject criteria is $\frac{1}{2} \pm \frac{1}{2}$) inch, depending upon the strength of the carcass.

One commercial carrier experienced approximately forty failures in the last year before using holography. Then, using holography and the above described more liberal accept/reject criteria which was instituted, that airline experienced no other tire failures for over a year as a result of separation.

A second airline company has experienced approximately a dozen failures in a single year prior to requiring holography. They had established a $\frac{1}{2}$ inch diameter separation accept/reject criteria which was probably a bit too severe. With holography, that accept/reject criteria was liberalized slightly, and evidence now is that the airline did not experience any additional failures as a result of the new criteria.

So again, most of the committee discussion centered around the realism of the accept/reject criteria and the liberalization from ($\frac{1}{2} \pm \frac{1}{4}$) to ($\frac{1}{2} \pm \frac{1}{2}$).

The committee then moved on to discuss a feeling of disappointment that so few of the rubber companies had taken part in, and actively participated in any previous sessions. One of the suggestions which came out of our discussion is that a possible alternative to the procedure which we have used in the past four symposia, would be to allow individuals to present their views without having them published.

STANDARDS WORKING GROUP REPORT

R. Yeager, Chairman
Goodyear Tire & Rubber Co.
1144 E. Market Street
Akron, Ohio

Good morning. Ladies and Gentlemen. I'd like to first thank Paul Vogel for his time spent in preparing and conducting this Symposium and also the assistance given by Mr. Merhib and Mr. McConnell. The standards working group met for nearly two hours yesterday. We had nine participants in the field of tire NDI specialists representing four of the major rubber companies, the Army, the Navy, FAA, and independents. I think this was a milestone since it was the first committee meeting to discuss standards here. It was generally concluded that the field of standards is a very complex subject and no overnight breakthroughs are going to happen. The first order of business is an attempt to set goals for this committee. These can be in the area of providing a sample block to evaluate X-ray, ultrasonics, and holography. These three were considered plus any new development type of nondestructive technique that may come up. The sample block could be a step block with built-in separations and this could be used within the industry to coordinate a standard type of testing and to give the suppliers a suitable sample to initially evaluate their products. From all of this will probably evolve a glossary of terms and additional terms which could be applied at any later date. I plan on working with the participants in order to arrive at a mutually agreeable set of goals, glossary of terms, and finally establishing a test standard block. These could then be presented at a later time. I would recommend a national meeting on a less frequent basis and then probably have a committee meeting whenever anything of interest or value is established.

Q: Why a block instead of a tire, for instance?
A: I think a block is easier to use. It's a first step. For example, if you use a block, you could have a series of them, not necessarily just one. You could have a series of blocks with different types of separations built into them or different types of defects or anomalies whatever we agree on. You could set this up very quickly and run tests on it. It would give you a working knowledge. Within the industry, for example, you could sent it from plant to plant, among the nondestructive testing pieces of equipment. Let them try it out. It would be easier to handle. A tire I think is a long step because you are going to have to agree on bringing a mold in and the type of tire, whether it be a passenger, truck, airplane, military or retread. I just think right now at this time a tire would be very difficult to agree on. The type of tire would be a very long range program to come up with a standard. It would certainly be a worthwhile goal.

QUALIFICATION WORKING GROUP REPORT

G. McConnell
Naval Air Development Center
Warminster, PA

My thanks to Air Treads, Piedmont Airlines, BF Goodrich, and the Naval Air Rework Facility at North Island, for participating in the Qualification Working Group. We unfortunately didn't have a good cross section of the tire industry or rubber industry. Our representation was primarily aircraft-related people.

Since most nondestructive inspection processing does not produce subjective evidence of the product quality, the individual inspectors' knowledge and skill combine to establish the sensitivity and reliability of the inspection process. Therefore, most commercial organizations, all DoD departments and agencies, and all DoD contractors have mandatory standards which establish the minimum requirements for training, qualifying, examining, and certifying nondestructive inspection personnel. Our working group discussed existing standards and the most prominent of which are the American Society of Nondestructive Testing recommended practice, SNT-TCIA, and MIL Standard 410D. We talked about equipment qualification and the need for uniformity among the many facilities performing nondestructive tire inspection. The operation of nondestructive inspection effort is often restricted for the following reasons. The speciality is just too new and not properly understood by supervision and management. My experience shows that often direct supervision has no real appreciation for the methods, they are not trained, and management is further removed and is worse in that respect. Inspectors often perform the nondestructive work as a collateral duty and this tends to neutralize their proficiency. Many organizations have no formal inspector training programs. I have had a document shown to me from many of the tire companies so the retreaders that do military work have a document for standard qualification but, I haven't seen any from the commercial tire companies. The final thing is that quality assurance people often have no real control of nondestructive processing. During our discussion,

many cases have been cited to demonstrate improved reliability because of nondestructive inspection but we also recognize that we do not always have the desired capability-uniformity among facilities. For instance, one organization may have a half a dozen or a dozen different nondestructive and test facilities and they have personal preferences. Not all of them but some organizations have personal preferences for the quality of work that comes from one or two or several of their facilities. The conclusions and recommendations are that qualification and certification standards are necessary. That we should use common qualification certification standards for commercial and military aircraft tires. Separate qualification certification should be required for each inspection method, and MIL Standard 410D should be updated to include holography.

In conclusion, we express our thanks to Paul Vogel; the Army Materials and Mechanics Research Center, the host activity; for conducting this Symposium. We would like to ask the Army to consider a request. I think most of you are familiar with a report that Paul wrote that was published in Rubber Age about five years ago. Now with four symposia behind us and five years of progress and new techniques, we feel an update of Paul's report would be of great value to the entire rubber community. Mr. Vogel is knowledgeable in these fields, and his tact and respect for industrial competence gives him a unique qualification and ability to gather together the most information into an entire NDI report. So since we are deeply concerned with equipment and techniques, we list as an Army need an updated state-of-the-art survey; and we would like Paul to do this if possible. We would like to see as much statistical information as is available to assist in understanding the capabilities of the various inspection methods.

Thank you

X-RAY WORKING GROUP REPORT

D. T. Greene, Chairman
Imagex, Inc.
Mentor, Ohio

The following recommendations are respectfully submitted:

1.0 The need for standards for evaluating performance of X-ray equipment is recognized.

1.1 Suggested method is to have a group of interested and knowledgeable people from the tire industry, the X-ray manufacturers, concerned Government agencies, with participation by a member of a suitable existing standards organization, hold two or more one-day meetings at monthly intervals to formulate the type of standards required to properly judge performance of X-ray equipment.

1.2 Any necessary funding for preparation of standard samples as decided by this group is unlikely to be provided solely, if at all, by the tire and X-ray manufacturers, and should preferably come from interested federal agencies.

1.3 It is not intended to imply that any standards will be set up, or judgements made, about the quality of finished product as a result of the above, but rather that the results be confined to the evaluation solely of the X-ray testing equipment itself.

2.0 We recognize a change in X-ray technology which will permit very rapid examination of certain structural features of tires without the use of human operators at a much lower cost per tire, and which provides outputs in digital form. We suggest that the impact of the new technology be recognized and that DoD inform itself on this subject.

3.0 We believe that there would be advantages in a combined program that would simultaneously apply the several NDI systems, such as X-ray, force variation, ultrasonics and holography, to study how they complement each other. A test series where a large number of tires is analyzed by all of these methods, taking into account the recent availability of modern X-ray and holographic equipment which can provide digital rather than subjective data, should provide valuable correlation information which seems lacking at present. We strongly feel that any single test method is most unlikely to be a panacea, and that some combination of methods is the proper route for the future. A test program as outlined, using only the most modern equipment available, should point out the proper future direction.

CHAPTER V

PANEL DISCUSSION

Mr. Kyriakides: I would like to make some comments to the participants involved. I would say at this time it is very important that the proceedings consider the problems of the consumer and the big problem to the consumer is the problem of radial tires. You are aware that now, over 80% of new cars are equipped with radial tires, and since this change we are taking is very, very fast. In a very short time, we will face a real problem. And the real problem in radial tires is belt edge separation. This type of failure in the radial tires presents a belt edge separation, and this separation is due to curing of compound. The radial belt edge due to flexing will start very, very slow tearing and this type of tearing will extend in time and is to be in direct proportion to the age of the compound. The method just to detect and to establish a relationship between this propagation of tearing or separation in the radial belt will be extremely important. We performed some tests, and I was a little disappointed with that I didn't hear it now. . . . Hear about infrared method which should also be considered official. All these methods presented yesterday, they were very important, very interesting, very valid results but at the same time we got some very interesting results on infrared methods also at Monsanto. The problem on infrared is to establish a warm-up period which could be very short in order to warm-up the tire and after this we got very promising results. This doesn't mean it will be the method of the future, but I would say that this method should be considered official also as a nondestructive test which seems to be promising also besides programming, holographic, ultrasonic and X-ray technique.

Mr. Vogel: We have a partial answer to your question. We are very active in infrared at the Army Materials and Mechanics Research Center. I wonder, you have explored with Monsanto an active infrared test where you inject heat temporarily and then look for the flaw in the cooling process. We have just finished a preliminary study with infrared for the Navy on a part that resembles a massive 5-steel ply tire. We are developing a new instrument that will hopefully do a very rapid macro scan of that so that we can then get down and do the micro with a smaller infrared instrument. These are two instruments we have under development, one is a pyroelectric vidicon which will do away with the cooling problem involved in the present infrared techniques and the other one is a single-line scanner. We aimed initially at looking at the integrity of the long spars, the rotors, on helicopters. It would also be ideal for looking at the aircraft wings for water content, for example, which the airline people say is a tremendous problem. When they are carrying tons of water, that's tons of fuel that they are not carrying. There, this single line

scanner would be of advantage too. We would like to hear more of your problem and your interest in infrared and possibly pursue this as an Army need if you could maybe boil the problem down to a few paragraphs and drop us a note. We may have the equipment just down the road a little bit that could answer your need.

Mr. Shaver: In regard to what's been said about future symposiums, and participation of many papers and so forth, we have all kinds of problems, individually and company, not the least of which the gentlemen of Goodyear pointed out that we have a lot of different hats to wear. Some of our people have to wear so many that they've worn their hair off. In the Atlanta symposium I presented a paper on what we were doing in holography and when the next symposium happened in Akron I told myself well we're not doing anything new, so it will just be a rehash of the old paper. When Paul sent out the deal on this one, the same thinking process went through my mind. But I think really that what I need to do is to plead guilty to complacency and plead guilty to just wanting to come along and take the easy route out and listen to what other people have to say and present. I plead guilty to not having a full realization that everybody that comes to these things has some kind of obligation to put a little into the pot, rather than always reach in and take something out. Pretty soon the cookie jar runs dry. There is a slight indication made that the interest in these things is waning and it really shouldn't be but we are all trying to come and take something out of the cookie jar and not put anything back in.

Perhaps it is incorrect to think that we're not doing anything new at Air Tread, so what is there for you to talk about? Yet, it seems that even people like Dr. Kruger in Germany on truck tires is interested in what we are doing in airplane tires. So maybe we're not doing so many *new* things but we're doing *more* and more of it. I think it would be of some interest for people to know to what gradually growing extent we're getting into nondestructive testing. We operate machines and tire plants on a continuing day-in-day-out production basis. And by the next symposium there's just no telling to what deeper extent we will be into nondestructive testing. I even wondered if we should try to broaden the scope a little bit. And instead of just tires, go tires and wheels. But then I recognize the fact that we are not just talking airplane tires. We at Air Treads are at the present time being forced into doing such interesting NDI work on wheels in that we are having to make our own machines. We have a machine right now about 90% complete that will do what the Dr. Foster system has done so well for SAS in automated scanning of the tube wheel-well

The thing that we're doing different is instead of having to hand-scan that very important place which is the bead seal radius, our machine is going to turn that corner and come on up the wheel flange. That is just something that we must do and we are doing it in aircraft wheel NDI. There is enough interest in what we have so far that we have some airlines extremely interested in having us make this. But I think I can assure you that when the next symposium is held, and the invitation for papers comes up, Paul, I will look at it in a new light and not try to be as lazy as I've been in the past and I will see if I can put a cookie back into the jar.

Comment: In casual conversation with major tire manufacturer employees, they really are under pressure not to come to this environment and they have even had subtle threats of job loss if they violate certain rules set up by management. So I think we're talking to the wrong people. There is upper management putting planks on this and how do you get to them. Everyone appears to know that there is a threat.

Mr. Merhib: Yes, that is a basic problem. I don't know how you reach those people, maybe if we had their names we could send them correspondence and hope that they'll read that it stresses the desirability of having their points of view presented and try to convince them that it is in their best interest to have someone here and speaking publicly. It is not easy, you're in a competitive field and there is a lot of secrecy.

Mr. Marx: I'm not in any position to speak for the tire companies but I can try though. When the call for papers goes out, if you direct some to me I will see what I can do to get some cooperation from the tire companies.

Comment: I think the point has to be made here that I am not too sure if I totally agree on the pressure not to attend. If there was pressure not to attend, we would not be here. As an industry we're "close to the chest" on what we tell our friends across town and so forth. It seems that Michelin has indicated that perhaps more than anybody in the industry, but I have to object to the pressure not to be here. I think the tire companies do very well in supporting the various societies. I think that point has to be made.

Comment: One of the gentlemen mentioned during his talk that he was disappointed about the turnout at the committee meetings. We were extremely disappointed in the fact that we were only able to attend one of these meetings. Some of us would like to attend most of the different group meetings but we can't do it because they're all held at the same time. I would have liked to attend two or three but I couldn't.

Mr. Merhib: We do have a restriction on time. I would like to open the floor to questions to see how to handle this sort of thing. We have a fixed amount of time and we have

many committees. You just have to pick one, unless you extend the working group meetings over a long period of time, or change the whole format. For example, we could hold the working groups as we're holding them now but instead of only the reports would have full discussions of holography, then ultrasonics, then X-ray, then standards, etc., but you would extend your period of time into days, I'm sure. And we just don't have that sort of time.

Question: Do we need to hold these group meetings after the program, or can they be held during the program? Maybe one-half hour or forty-five minutes before lunch each day or maybe twice a day.

Mr. Merhib: You mean the working group meetings? No, they don't have to be held after the meetings, that is just the format that we have used three times before, and even with its drawbacks, there has been no strong objection.

Comment: I would like to make a suggestion that the first few days of the session, could the working meetings be held in the evenings? Most of us, I won't speak for all of us, but most of us spend our evenings looking at the tall end of the glass until about two in the morning. We could have as many as two sessions a night starting at the very first night because much of what is discussed in these working groups is stuff people have been thinking about before they came and does not always relate to the vendor type speeches that we hear anyways. And I would suggest that each evening we have two sessions. Say one starting out at about 7:30 and the other one at 9:30 so that everyone can attend. It was always a great deal of concern to me that I can't attend my competitors' sessions. I must be at my own. I would suggest that on the third evening, many of the people have already left, so that the very first few days, there be at least two or three sessions each evening and that we fill the evenings up with informal discussions and I would like to suggest that those discussions be closed door. In the optical society there are indeed locked door sessions. No members of the press are allowed and there is a general understanding amongst the members that are there that, that which they discuss is not carried out and discussed further. You would be rather surprised as to how well that is adhered to because, in the next session, the man who shoots off his mouth is not invited. And the people who really have an active contribution to it, as Carroll says, who really want to put a cookie into the jar, attend these sessions. It is unbelievable as to what is accomplished in the optical society meetings in the late hours. As a matter of fact on some occasions, until one or two in the morning. That is when the real donnybrooks take place. After holography was first invented, in that field and optics, I'll tell you there wasn't anyone of importance in the whole damn field who didn't attend that. You couldn't get standing room only, because everyone was so eager to hear what the other guy was going to say. At those times, everyone came—Dupont, Xerox, right down, IBM, RCA, and all the major universities, and

everyone who had two cents to put in was damn eager and in fact those were the sessions, which they really prodded people like Kodak. "What is your new film? What are you coming out with? The hell with using what you have got now. What do you have on the burner for next year?" "Where's the AGFA man? Get him in here," and they would start like that. These people, as compared to the tire industry, are not talking about individual compounding or specific constructions or specific test programs on the track but rather taking the situation of – well let's take Ed Pollard in San Angelo. Ed, what have you used down there? What are you happy with? We don't need to know the specific details but how do you feel about this sort of thing. And let's get Glen Gray right up here beside him and I think you fellows might be a little surprised at how much could be gained from that *without* disclosing much of the confidential information. No one is more appreciative of the confidentiality than Hans Rottenkolber, Jim Thompson and myself. If you guys look in a dusty bar somewhere this week, most likely the three of us are together having a drink. We don't exchange circuit diagrams but we do exchange a lot of our feelings and I think in a way that we helped each other quite a bit. I think a lot could be done in this form without worrying about disclosing very much information because no one is more aware of the profit motive than guys like Jim or me. If he gets a little ahead of me on one circuit and I a little ahead of him on one, it's where the next machine sale is going. That's the same thing with you fellows on the tires. I think you have less danger –maybe more to lose than we have–but you have less danger than fellows like Jim or me. If Jim gets up a little earlier than me the next day, there goes my next machine sale, and Hans Rottenkolber is breathing on us hot and heavy every day of the week and besides his time shift– his jet lag–is five hours, he's up five hours earlier than Jim or me. Now I would like you fellows to comment on that, as to whether there might be the kind of optical society meetings, the kind of ones in which you throw out people. It almost gets defensive in the beginning when you say who are you? Who are you with? You don't belong in this session. This is a private session and another guy comes in who has not been very active in the sessions in the past and as Carroll says, he hasn't put his cookie in the jar, so the hell with him too! so in these sessions much can be gained, and I think a more realistic perspective can be had. Are there any comments on that or anything?

Mr. Yeager: I go along with the idea about having night time evening committee meetings because things are changing. Five or six years ago, holography wasn't as well established, not as many studies, and I would have liked to have attended some of the other committees and I couldn't, I think the idea of having them in the evening would be great. Maybe two each evening for the first two evenings.

The other thing is the quality of the program. I have attended a lot of symposia on the west coast when I was working in the aircraft industry and also on the east coast.

It seems like there is a tremendous difference. On the west coast, the attendees are much more critical. I don't mean to be sarcastic and facetious but they are more critical of the papers that are given; and, when they are critical of the paper, I think that if it is done on a constructive criticism, rather than just to knock somebody, I believe that you will enrich the symposium, you will make it a better quality. When you make it a better quality, you will get more people to attend. Keep it on a technical level, rather than political level. Sure, there will probably be some question on just what you can give, you don't give away the secrets. I really don't believe the secret stuff. That I have never gone for. I think it is all ridiculous anyway. While I worked in the aircraft industry, just for example, just to show you something that is so ridiculous. They used to make us lock all our cabinets and put the secret bar on it. And when you unlocked it, you took the secret bar off and you put the lock on the inside and you closed the cabinet. And that was supposed to be safe. But when you left, somebody could walk in and replace that lock with their lock. You would lock that secret cabinet up at the end of the evening with their lock, and they could come in that night and take anything they wanted out and put your lock back on. You would never even know anything was missing. This is how ridiculous I feel, that the secret thing can be carried and I think that if we become more critical of what type of papers are given, and if we are more outspoken, and work together, I think there will be a more mutual trust between say the companies and the Government. There would be more open discussion; I think people would be in a more relaxed atmosphere. It's always been said that the Government only fills vacuum. If we create the vacuum then I think the Government rules will probably fall in. Let's say for example thirty or forty years ago would have been kind of ridiculous to try and design a supersonic transport. The state-of-the-art wasn't there and I think the state-of-the-art isn't there today to have the 100% inspection of any type of tire. We've tested probably, holography wise, pretty close to a million tires. We have a lot of information. I can't say too many things for sure. I'm not trying to hedge on it. I just don't know. I would ask anyone if they could say anything for sure in NDI. What a separation means exactly, how did it get there, and why. We can build certain types of tires that will do certain types of things but nobody builds bad tires on purpose. I think we should have more criticism to try to upgrade the quality of the meetings, don't be afraid to say something. If somebody gets up and says something that's off color or wrong, call them down on it. Then I think at the next meeting, you will have a better quality paper given and it will follow that with a better quality of paper you will have more attendees.

Mr. Merhib: Regarding the next symposium, please communicate your suggestions for a possible location to the time and place committee chairman Mr. Jack Price of Air Tread. Mr. Price is here I believe. So if you do want one and have any comments to make regarding another symposium Jack Price will be happy to accept those comments

APPENDIX — ATTENDANCE ROSTER

4TH SYMPOSIUM OF NONDESTRUCTIVE TESTING OF TIRES

BUFFALO, N. Y.

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23-25 May 1978

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Akron, Ohio 44316

A. Stiebel
Uniroyal
6600 E. Jefferson
Detroit, Michigan 48232

C. L. Swinehart
Federal Aviation Admin.
Cleveland Hopkins Int. Airport
Cleveland, Ohio 44135

J. T. Thomasson
Newport Research Corp.
18235 Mt. Baldy Circle
Fountain Valley, California 9104?

N. M. Trivisonno
B. F. Goodrich Res. & Develop.
9921 Brecksville Road
Brecksville, Ohio 44141

B. Thwaite
Dunlop Tire & Rubber Corp.
Sheridan Dr. & River Roads
P. O. Box 1109
Buffalo, New York 14240

K. Tyran
Swissair, TZMPP
Zurich Airport
Zurich Airport, Switzerland CH-8053

P. E. J. Vogel
DRXMR-MI
Army Materials & Mechanics Research Center
Watertown, Massachusetts 02172
now: Star Rt. 6, Box 161
        Dunnellon, FL 32630

R. J. Watts
U. S. Army Tank-Automotive Res. & Dev. Command
Warren, Michigan 48078

J. R. Weber
General Tire
1 General Street
Akron, Ohio 44329

J. F. Wood
Piedmont Airlines
Smith Reynolds Airport
Winston-Salem, N. Carolina 27102

R. W. Yeager
Goodyear Tire & Rubber Co.
1144 E. Market Street D/460G
Akron, Ohio 44316

D. I. Zimmerman
The Kelly-Springfield Tire Co.
P. O. Box 300, Kelly Road
Cumberland, Maryland 21502

T. R. Zimmerman
Industrial Holographics, Inc.
2247 Star Court
Auburn Heights, Michigan 48057

WORKING GROUP VIEWS. Center: Working Group Presenters; (Left to Right) Mr. Yeager, Standards;
Mr. McConnell, Qualification; Mr. Merhib, Chairman; Dr. Grant, Holography; Mr. Kraska, Ultrasound;
not shown, Mr. Greene, X-ray.

Left to Right Top: banquet headtable, Mr. Hampton, Mr. Yeager, Mr. Henry, COL Benoit, Mr. Lavery; COL Benoit, Mr. Fahey, Mr. Henry, Mr. Lavery; Mr. Merhib; Center: The Harmony Heroes; view of de-watered Niagara Falls as presented by Mr. Henry; Kathy Seege and Sue Coppella of the Executive Hotel assisted in planning the banquet and arrangements; Bottom: Mr. and Mrs. Price; banquet scene; Mr. Vogel.

Top to Bottom Left: Mr. Kyriakides, Dr. Grant, Mr. Hampton, Prof. Rottenkolber; Center: COL Benoit, symposium view, Prof. Clark; Right: Mr. Lavery, Mr. Klaasen, Mr. Lyngsgaard, Mr. Stiebel.

Top to Bottom Left: Mr. Yeager, Mr. Watts, Dr. Johnson, Mr. Zimmerman; Center: Mr. Neuhaus, symposium view, Mr. Bogdan; Right: Dr. Chait, Mr. Ritchie, Mr. Plank, Mr. Haskell.